Final Report

Evaluation of the 1990 Drainage Management Plan For the Westside San Joaquin Valley, California

Submitted to the Management Group of

The San Joaquin Valley Drainage Implementation Program

January 2000

Prepared by

SJVDIP and University of California
Ad Hoc Coordination Committee

DISCLAIMER

This report presents the results of a review conducted by an Ad Hoc Coordination Committee for the Federal-State Interagency San Joaquin Valley Drainage Implementation Program. The Ad Hoc Coordination Committee was formed by the University of California Salinity/Drainage Program and the SJVDIP. The purpose of the report is to provide the Drainage Program agencies with information for consideration in updating alternatives for agricultural drainage water management. This report was submitted to the SJVDIP Management Group for their consideration. Publication of any findings or recommendations in this report should not be construed as representing the concurrence of the Program agencies. No detailed coordination or integration programs between government agencies and local districts regarding these findings and recommendations have been developed. No agreements of any kind have been made or entered into by any parties with respect to any combination of action statements appearing in this report. The statements appearing in the report do not carry any obligation by any party, nor have any legal standing. Also, mention of trade names or commercial products does not constitute agency endorsement or recommendation.

The San Joaquin Valley Drainage Implementation Program was established in 1991 as a cooperative effort of the United States Bureau of Reclamation, United States Fish and Wildlife Service, United States Geological Survey, United States Department of Agriculture-Natural Resources Conservation Service, California State Water Resources Control Board, California Department of Fish and Game, California Department of Food and Agriculture, and the California Department of Water Resources.

For More Information Contact:

Manucher Alemi, Coordinator
The San Joaquin Valley Drainage Implementation Program
Department of Water Resources
1020 Ninth Street, Third Floor
Sacramento, California 95814
(916) 327-1630
malemi@water.ca.gov
Or visit the SJVDIP Internet Site at:
http://wwwdpla.water.ca.gov/agriculture/drainage/implementation/hq/title.htm

AHCC Committee Members

Members

Dr. Manucher Alemi, San Joaquin Valley Drainage Implementation Program, DWR
Mr. Tad Bell, Department of Food and Agriculture
Dr. Vashek Cervinka, Department of Water Resources
Mr. Doug Davis, Tulare Lake Drainage District
Mr. Mike Delamore, U.S. Bureau of Reclamation
Dr. Neil Dubrovsky, U.S. Geological Survey
Dr. Graham Fogg, UC Davis
Dr. Steve Grattan, UC Davis
Dr. Blaine Hansen, UC Davis
Dr. Keith Knapp, UC Riverside
Dr. John Letey, UC Riverside
Mr. Joseph McGahan, Grasslands Area Farmers
Mr. Dale Mitchell, Department of Fish and Game
Mr. Walt Shannon, State Water Resources Control Board
Mr. Ken Swanson, Westlands Water District
Dr. Ken Tanji, UC Davis
Mr. Arthur Unger, M.D. Private Citizen
Dr. Wesley Wallender, UC Davis

Major Contributors:

Mr. Wayne Verrill, San Joaquin Valley Drainage Implementation Program, DWR
Mr. Larry Rollins, Research Writer, Davis, California

List of Acronyms

ac-ft/a/y	acre-feet per acre per year
ac-ft/ac	acre-feet per acre
af/a	acre-feet per acre
af/a/y	acre-feet per acre per year
AHCC	Ad Hoc Coordination Committee
CDI	carbon aerogel capacitative deionization
CEQA	California Environmental Quality Act
CIMIS	California Irrigation Management Information System
CVAPO	Central Valley Agricultural Evaporation Pond Operators
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
CVRWQCB	Central Valley Regional Water Quality Control Board
DFA	Department of Food and Agriculture
DFG	Department of Fish and Game
DOI	Department of Interior
DR	drainage water reuse
$\mathbf{D^{reg}}$	desired reduction level
dS/m	decisiemens per meter
DWR	Department of Water Resources
DWT	drainage water treatment
EA	Environmental Assessment
EC	electrical conductivity
EP	evaporation pond
EPA	Environmental Protection Agency
ET	evapotranspiration
EWMP	Efficient Water Management Practices
FONSI	Finding of No Significant Impact
ft.	feet
gal/day	gallon(s) per day
GM	groundwater management
IFDM	Integrated on-farm drainage management
JPA	Joint Powers Authority
$\mathbf{K_C}$	crop coefficients
LHWD	Lost Hills Water District
LR	land retirement
MG	Management Group
mg/l	milligram per liter
MOU	Memorandum of Understanding
MP	Management Plan
NRCS	U.S. Natural Resources Conservation Service
PL 95-46	Public Law 95-46
ppb	parts per billion

ppm	parts per million
RD	river discharge
RO	reverse osmosis
RWQCB	Regional Water Quality Control Board
Se	selenium
SJR	San Joaquin River
SJRMP-WQS	San Joaquin River Management Plan - Water Quality Subcommittee
SJV	San Joaquin Valley
SJVDIP	San Joaquin Valley Drainage Implementation Program
SJVDP	San Joaquin Valley Drainage Program
SLD	San Luis Drain
SLDMWA	San Luis and Delta Mendota Water Authority
SR	source reduction
$\mathbf{S^{reg}}$	regional aggregate marginal cost
SU	salt utilization
SWP	State Water Project
SWRCB	California State Water Resources Control Board
TC	technical committee
TDS	total dissolved solids
TLB	Tulare Lake Basin
TLDD	Tulare Lake Drainage District
USBLM	U.S. Bureau of Land Management
USBR	U.S. Bureau of Reclamation
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WADE	Westside Agricultural Drainage Economic Model
WDR	Waste Discharge Requirements
WWD	Westlands Water District

Table of Contents

1. Introduction

1990 Plan Update Process-The Activity Plan

In September 1990, *A Management Plan for Agricultural Subsurface Drainage and Related Problems on the Westside San Joaquin Valley* (Management Plan) was issued by an interagency program comprised of federal and State agencies. In the more than six years since Plan adoption, progress has been limited on full implementation and questions have arisen concerning some of its recommendations. The Management Plan states that "uncertainties in the scientific information base, plus difficulties in forecasting human events, necessitates that the Plan be updated from time to time as monitoring, additional studies, and local actions reveal new facts". On December 11, 1996, the Management Group of the San Joaquin Valley Drainage Implementation Program approved, in concept; a "Proposed Action Plan" advanced by an association of local districts, the University of California, and the California Department of Food and Agriculture, to update the Management Plan. This Activity Plan is carried out in three stages.

The first stage in updating the Management Plan consisted of two concurrent, coordinated, and independent tasks. One task was the preparation of reports on San Joaquin Valley drainage problem areas by three Subarea Committees which assessed the progress toward, and constraints of, adopting management recommendations in the Management Plan. The second task was preparation of eight Technical Committee reports on the current technical and economic evaluation of the management options proposed in the Management Plan together with salt utilization.

The second stage (this report) synthesized the information reported under activities of the first stage into a report, which identifies interactions between management options, trade-off between management options, and a set of recommendations based on technical and economic considerations. This task was accomplished by an Ad Hoc Coordination Committee.

The third stage is intended to use the recommendations formulated during the second stage along with input from the public sector to formulate an updated management plan and identify acceptable mechanisms conducive to adoption and voluntary implementation of the updated management plan.

In addition to evaluating and updating the 1990 Plan to resolve long-term drainage problems for the benefit of both agriculture and the environment in the San Joaquin Valley, cooperation of all stakeholders is necessary. The cooperative activity plan process is intended to remove constraints to implementation of drainage management and foster cooperation among stakeholders

Overview of AHCC Process*:*

The Ad Hoc Coordination Committee reviewed the Technical Committee reports, evaluated the interactions and trade-off of options by the Technical Committees, and developed a set of options encompassing all technical areas and made recommendations to the MG where feasible based on technical and economic considerations.

The Ad Hoc Coordination Committee members are individuals who served on the technical committees and include the chairs of the Technical Committees, SJVDIP agency staff members, one representative from each Subarea, and representatives of other stakeholders as selected by the Activity Manager and SJVDIP Coordinator.

Purpose of the Report

The purpose of this report is to review the subarea and technical reports, make an analysis of the findings of these reports, establish the interactions and linkages among options, and show trade off between options, make an economic analysis, and present a set of recommendations for implementation or further study.

2. The San Joaquin Valley Setting

Background

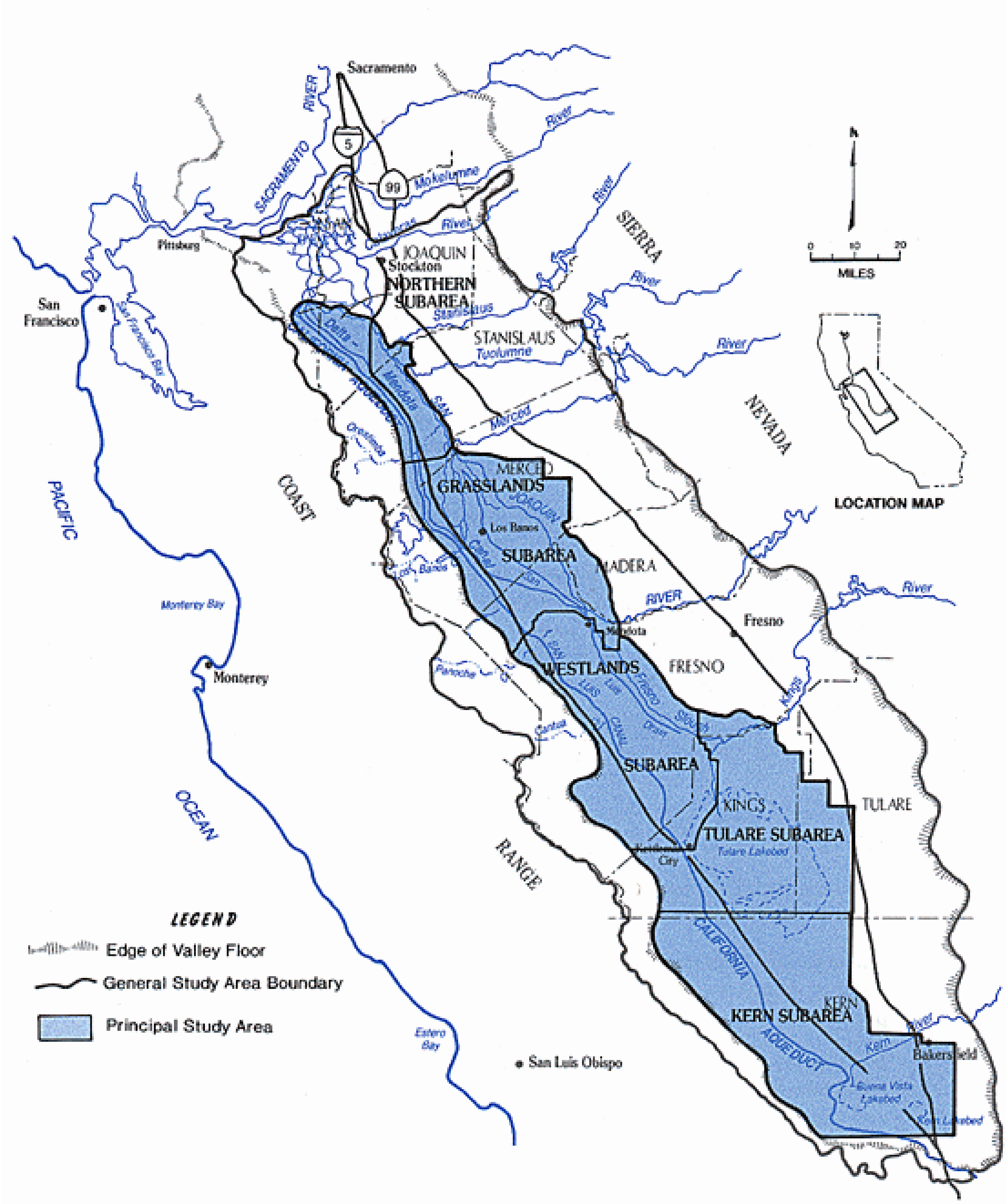
California's San Joaquin Valley is one of the world's most vital and productive farming areas. The westside of the San Joaquin Valley is a fertile yet arid landscape where commercial agriculture is viable only with supplemental irrigation. The importation of surface and groundwater for irrigation results in the application of salt to agricultural lands in addition to naturally occurring salt. The leaching requirement to remove salt from the crop root zone to maintain soil quality and productivity results in the deep percolation of applied water. Agricultural lands of the westside SJV are underlain by a low permeability clay layer without adequate drainage, causing a shallow water table to rise toward the soil surface. Waterlogging of the crop root zone and evapotranspiration of soil water from the shallow water table results in the accumulation of salts and potentially toxic trace elements in the crop root zone and shallow groundwater. High concentrations in drainage water of naturally occurring trace elements, such as selenium may pose a hazard to fish and wildlife when agricultural drainage waters are discharged to the surface. The San Joaquin Valley Drainage Program Studied the drainage problems in the mid 1980s. The SJVDP study areas shown in Figure 1.

Hydrogeologic Framework

The hydrogeologic framework in the western San Joaquin Valley is generally divided into three major zones (Figure 2): An upper unconfined to semi-confined aquifer system, a confining clay zone commonly referred to as "blue clay" or "Corcoran clay", and a confined aquifer system below the clay layer. In this report, the upper aquifer will be called the *semi-confined* system, and the sub-Corcoran aquifer will be called the *confined* system.

Three different hydrogeologic units are encountered in the shallow, semi-confined aquifer system. Coast range alluvium in the western part primarily consists of sand and gravel at the fan heads and along stream channels, and of silt and clay in the interfan and distal fan areas. Sierran sands (medium- to coarse- grained micaceous sands) occur toward the center of the Valley trough. Flood-basin deposits (moderately to densely compacted clays) lie in the immediate vicinity of the San Joaquin River in the San Joaquin Basin located in the trough of the Valley. Groundwater obtained from the Coast Range alluvium is mostly of poor water quality, particularly in the upper 50 feet. Where present at thickness of over 200 ft., groundwater is pumped from the Sierran sand (Gronberg et al., 1990). Its low salinity makes it well suited for irrigation purposes. Overall, the thickness of the semi-confined zone ranges from 400 feet near the valley trough to over 800 feet at the foot of the mountain range (Miller et al., 1971).

Figure 1
PROGRAM STUDY AREA



The Corcoran Clay Member of the Tulare Formation of Pleistocene age divides the groundwater flow system into an upper semi-confined zone and a lower confined zone. The Corcoran Clay is a regionally extensive lacustrine deposit of low permeability (Johnson et al., 1968) ranging in thickness from 20 feet to over 100 feet (Page, 1986). It is generally conceptualized as a single, continuous layer of very low hydraulic conductivity. However, detailed analyses of driller's well logs show that the Corcoran clay zone is not homogeneous. In some areas it is better characterized as a zone of multiple clay layers interbedded with more permeable materials.

The confined zone below the Corcoran clay consists primarily of flood-basin, deltaic, alluvial fan, and lacustrine deposits of the Tulare Formation (Bull and Miller, 1975). The thickness of the confined zone ranges from 570 to 2460 ft. (Williamson et al., 1989).

In the Tulare Basin, the semi-confined aquifer consists of the same three geo-hydrologic units found in the San Joaquin Basin, plus one additional unit, Tulare Lake sediments. The Tulare Basin is characterized by the presence of several dry lakebeds, including Tulare, Buena Vista, and Kern.

The marine formations, from which most of the Coast Range sediments and soils in the study area are derived, contain salts and potentially toxic trace elements, such as arsenic, boron, molybdenum, and selenium. When these soils are irrigated the substances dissolve and leach into the shallow groundwater (Gilliom, et al., 1989). Selenium is largely a westside phenomenon. Soils derived from Coast Range sediments are generally far saltier than soils formed from Sierran sediments. In fact, selenium in livestock feed grown in some areas of the eastern side of the valley is so low that it must be added to the livestock diet.

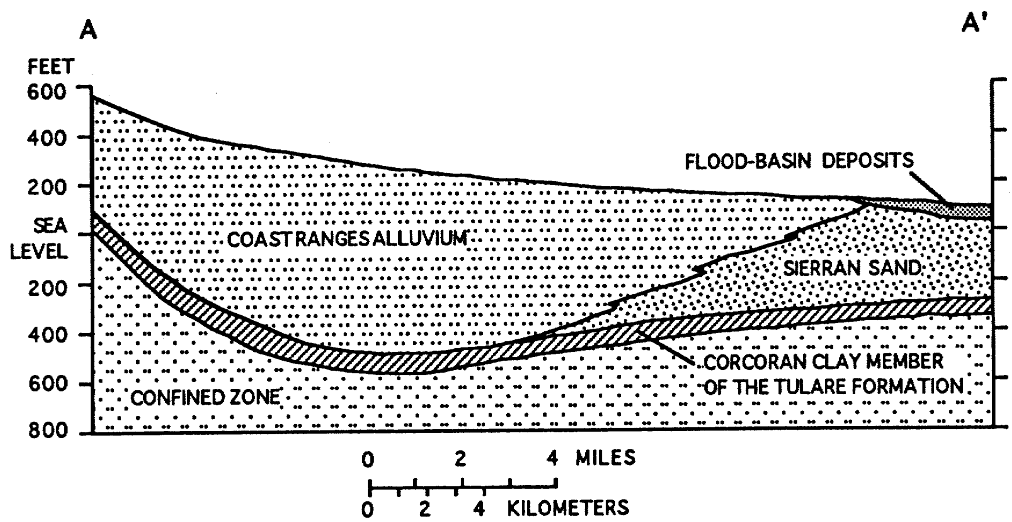


Figure 2. Schematic cross section (west to east) through the western San Joaquin Valley.

Climate. The climate of the western San Joaquin Valley is semiarid with annual precipitation ranging from 5 inches in the south to 10 inches in the north. Average annual pan evaporation reaches 60 inches (Rantz, 1969; Linsley et al., 1975). Precipitation occurs almost exclusively during the winter months and in early spring, when evaporation from the land surface and transpiration from plants is minimal. Precipitation is generally thought to be stored in the unsaturated zone during the winter months for plant uptake in the spring. Direct recharge from precipitation to groundwater has generally been assumed negligible (Davis and Poland, 1957; Gronberg and Belitz, 1992).

Irrigation. The present hydrology of the area is largely influenced by agricultural activities. Percolation of irrigation water through the unsaturated zone is the major recharge of the groundwater system. Irrigation water applied in the area is partly imported as surface water from the Sacramento and Feather River systems through the Delta-Mendota Canal and the California Aqueduct (Belitz and Phillips, 1995). The remainder of the irrigation water in the western San Joaquin Valley is pumped from groundwater. The amount of irrigation water applied depends on the irrigation method and irrigation efficiency, precipitation available for plant uptake, and the crop water requirement (which varies from crop to crop). Gronberg and Belitz (1992) estimated that the average irrigation amount in their study area (southern Grasslands and northern Westlands subarea) ranges from 1.5 ac-ft./ac to 2.2 ac-ft./ac. This range may vary depending on precipitation and temperature. Irrigation efficiencies (ratio of crop-water requirement to applied irrigation water) were estimated to range from 61 percent to 73 percent on an irrigation-district-wide basis. Average annual recharge rates to groundwater from applied irrigation water range from 0.5 ac-ft./ac to 1.0 ac-ft./ac.

Seepage from/to Rivers, Creeks, and Canals. The San Joaquin River and two westside tributaries, Salt Slough and Mud Slough, have been involved in the conveyance of discharged drainage. Since the 1950's, the San Joaquin River flows have been controlled by dams on tributaries and on the main stem. Water stored in Millerton Reservoir is diverted through the Friant-Kern and Madera canals. Irrigation water historically diverted from the lower reaches of the San Joaquin River was replaced with Central Valley Project water provided through the Delta-Mendota Canal, beginning in 1951. Now, the San Joaquin River is essentially dry much of the year from below Gravelly Ford to the point at which irrigation return flow and local runoff replenish the River. Development on major eastside tributaries has also reduced the flow of the San Joaquin River (SJVDP, 1990). Little is known about the amount of unintentional seepage (groundwater recharge/discharge) to and from either the San Joaquin River, Mud and Salt Slough, their tributaries, or the unlined canals delivering water from the major canals to the farms of the westside. Long-term aquifer testing near unlined canals indicates that there is the possibility of extensive hydraulic communication between groundwater and unlined canals (Schmidt, personnel communication, 1998). Ephemeral streams and creeks entering the westside from the Coastal Range also provide significant, but unspecified recharge to groundwater.

Subsurface Drainage. Subsurface drainage is the seepage of shallow groundwater to agricultural drains. Drainage becomes necessary where the water table is shallow enough to encroach on the root zone of agricultural crops potentially damaging these crops. In the most comprehensive, regional study of westside groundwater to date (Belitz and Phillips, 1995), it was estimated that total drainage in the study area accounted for 17 percent of all groundwater discharges.

Water Levels. Pumping of groundwater for irrigation from 1920 to 1950 drew groundwater levels down as much as 200 feet in large portions of the study area (Belitz and Heimes, 1990). High pumping costs, land subsidence, and declining water quality created a need for new water supplies. By 1951, Federal Central Valley Project water was being pumped from the Delta and delivered to the Northern and Grasslands subareas (Figure 1) through the Delta-Mendota Canal. By 1968, water was being delivered to the Westlands, Tulare, and Kern subareas (Figure 1) through facilities of the CVP's San Luis Unit and the State Water Project (SJVDP, 1990).

With a reliable supply of surface water, groundwater pumping for irrigation decreased and the groundwater reservoir gradually began to refill. The semiconfined aquifer above the Corcoran Clay then became fully saturated in much of the westside area. Water tables continued to rise, and the waterlogged area expanded. During the period 1977-1987, the area of 0-to-5-ft. depth to the water table expanded from 533,000 acres to 817,000 acres (Swain, 1990). The 1988-1993 drought significantly reduced this area. The most recent wet period 1995-1997 increased the total area affected by a water table of less than 5 feet depth from 321,000 acres in 1994 to 743,000 acres in 1997.

The water table generally slopes east northeastward. Toward the western edge of the San Joaquin Valley, other than at times of high rainfall, the water table slopes towards the Coast Range foothills and recharges groundwater pumped from the confined aquifer near the foothills. Thus, the highest elevation of the water table is generally found not at the boundary of the valley and the foothills, but several miles to the east of the valley boundary. Under current practices, with the high water table in the shallow groundwater, groundwater also flows from the westside toward the central part of the San Joaquin Valley.

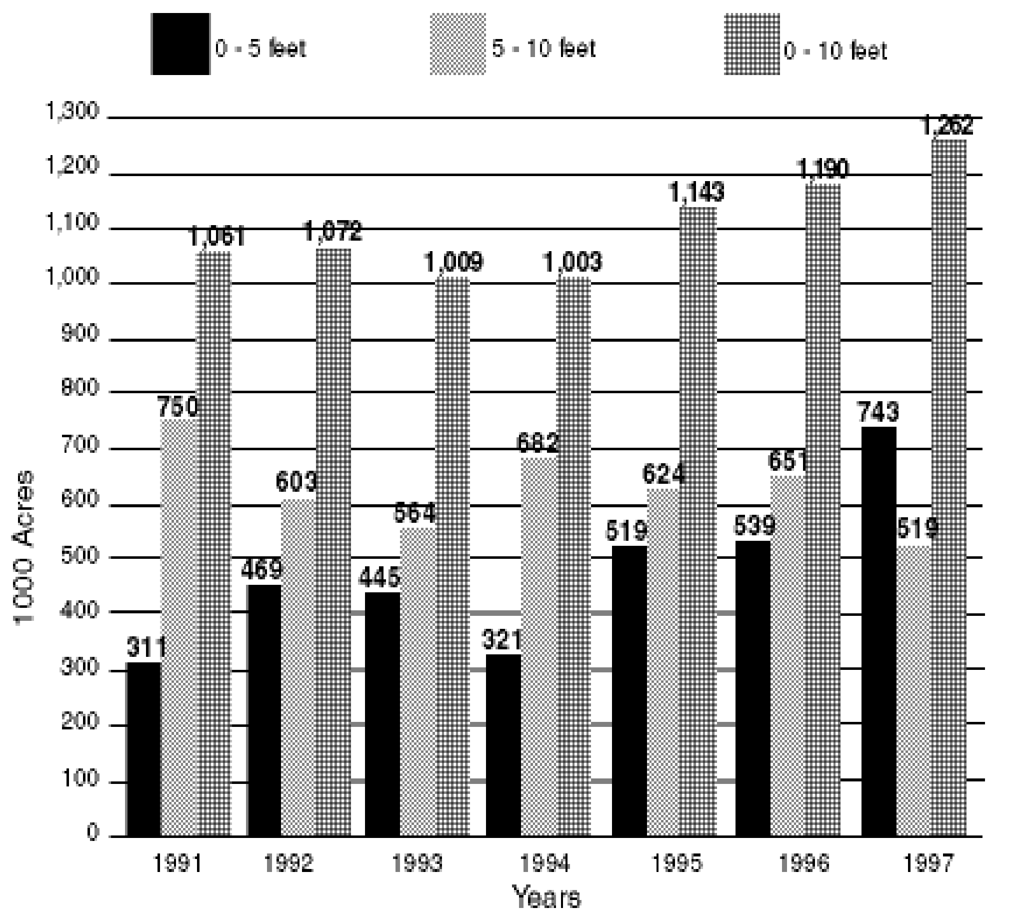
A computer simulation was conducted to investigate the effects of irrigation management on lateral groundwater flow in the west side of the Valley. The simulated evolution of the water table profile for this condition showed that the zone of shallow water continues to move up fan over the course of the simulation for 50 years. The portion of the area with a water table depth shallower than 7 feet expands in the up slope direction. The up gradient field which started as well aerated parcel, eventually has a high water table by the end of the 50-year simulation as well as a small portion of the field located immediately up slope. Without a change in management, the continued practice of irrigated agriculture in the Westside San Joaquin Valley is problematic.

Pumpage. Most groundwater pumped (approximately 80 percent; Belitz and Phillips, 1995) occurs from the deeper, confined aquifer below the Corcoran clay. Under current conditions, groundwater pumpage from the confined aquifer is balanced by leakage of groundwater from the semi-confined aquifer through the Corcoran clay (85 percent) and by groundwater inflows from the eastern part of the confined aquifer (15 percent), which underlies most of the San Joaquin Valley. Groundwater obtained from the Coast Range alluvium is mostly of poor, highly saline water quality, particularly in the upper 50 feet. Groundwater is pumped from the semi-confined Sierran sand only where present in a thickness greater than 200 ft., (Gronberg, et. al., 1989). The low salinity makes it well suited for irrigation purposes. Of the total groundwater pumped, only about 1/5 stems from the semi-confined Sierran sand aquifer. Pumped groundwater and drainage from the semi-confined aquifers is balanced by recharge from irrigation.

Salinity and Trace Elements

Salinization. The San Joaquin Valley Drainage Program Study Area on the westside of the San Joaquin Valley is about 2.3 million acres. (Figure 1). As an example, using 1980-1985 data (SJVDP Technical Information Record, 1990), SJVDP estimated the annual increase in dissolved solids (salts) in the semi-confined aquifer on 2.3 million acres of irrigated lands on the westside of the San Joaquin Valley to be about 6.115 million tons. The sources of this salt accumulation is imported water from the Delta (1.766 million tons), groundwater pumped from the confined aquifer (0.968), local stream diversion (0.301), lateral and local stream inflow (0.155), canal losses and precipitation (0.100), and native salt solubilization (2.825).

Shallow Groundwater Table and Water Quality. DWR and local agencies monitor the depth of the shallow groundwater table from the ground surface at over 1,000 locations on the west side of the Valley twice each year. The water table is shallowest in early spring as a result of winter rainfall and preplant irrigations. In many areas, the water table lowers with time during the growing season due to reduced percolation from irrigation, caused by decreasing infiltration rates, increased shallow groundwater use by crops, and natural drainage through the Corcoran Clay layer. Areas having shallow water depths are shown in Figure 3.



Areas of shallow groundwater in Grasslands, Westlands, Tulare, and Kern subareas combined. (Source: DWR data)

Figure 3. Shallow groundwater depth in the San Joaquin Valley

SJVDP conducted a regional water quality evaluation of key constituent concentrations, including distribution in shallow groundwater at depths that could affect the quality of drainage water. Salinity, boron, and selenium were considered to be the most critical constituents, with salinity and boron affecting agriculture and selenium affecting wildlife. The data were collected during 1984-1989 with a one-time synoptic water quality survey in the southern part of the Valley in 1990. SJVDP monitoring was a reconnaissance level effort at the regional scale, thus site-specific data is needed for more accurate characterization. The shallow groundwater data for the westside San Joaquin Valley are shown in Table 1.

Table 1. Areas with shallow water table between 0-5 feet and salinity, selenium, and boron concentration in shallow groundwater, 1984-1990 data.

Constituent	Concentration	Area, acres
salinity	> 2500 ppm	662,000
boron	> 2 ppm	882,000
selenium	5-20 ppb	553,000
	20-50 ppb	405,000
	50-200 ppb	265,000
	> 200 ppb	55,000

Selenium has been monitored in subsurface drainage water and in the San Joaquin River and its tributaries (DWR, 1993 and CVRWQCB, 1998). The mean of selenium concentration in the SJR at Vernalis, in drainage water from the Drainage Problem areas in the Grasslands subarea, and the central and southern parts of the Valley for 1993 are shown in Table 2.

Table 2- 1993 TDS and selenium data

Location	Range of Se ppb	Mean of Se ppb
SJR, Vernalis *		1.9
Drainage Problem Area *		79
Central (Dos Palos to Mendota)**	9-187	69
Southern (Hanford to Bakersfield)**	1-454	66

* CVRWQCB, 1998
**DWR, 1993

Currently, limited drainage water disposal is permitted into the San Joaquin River from areas in the northern part of the SJV and to evaporation ponds in the Tulare/Kern subarea.

Planning for Drainage Management in the San Joaquin Valley

Pre-Kesterson Drainage Planning. Federal and State agencies have long recognized the need for proper drainage. Historically, farmers addressed the drainage problem by installing subsurface drainage systems to collect shallow groundwater and transport it away from the fields for disposal. Lack of disposal capability, however, has limited installation of subsurface drainage systems. Because this is a regional problem and affects an area that exceeds local jurisdictions, federal and State agencies assumed a lead role in seeking a regional solution (SJVIDP, 1979).

Planning for drainage facilities to serve the Valley began in the mid-1950s. The Bureau's feasibility report, *San Luis Unit, Central Valley Project: A Report on the Feasibility of Water Supply Development, 1956*, described the proposed drain as an unlined ditch that would drain 96,000 acres. The California Legislature ordered a study in 1956 of a "comprehensive master drainage works system" (California Legislature, 1957).

In 1957, the Department of Water Resources published its *California Water Plan*, which outlined the State Water Project (DWR, 1957). This Plan included a master drain extending from near the Buena Vista lakebed in Tulare Basin to the Delta. In 1960, California voters approved the Burns-Porter Act authorizing State Water Project financing and construction of "facilities for removal of drainage water from the Valley" (SJVIDP, 1979).

Congress enacted Public Law 86-488 in 1960, authorizing construction of the San Luis Unit of the Central Valley Project. The Bureau was authorized to either participate with the State in a master drain project or construct the San Luis Interceptor Drain to serve the drainage needs of the San Luis Unit. The project was revised in 1962 to a concrete-lined canal that would drain 300,000 acres. In 1964, the plans included a flow regulatory reservoir (Kesterson) to control discharge to the Delta and to minimize the size of the drain facility. The State participated initially in joint planning of the master drain but withdrew in 1964 due to lack of funding for the program.

The Bureau began constructing the San Luis Interceptor Drain (shortened to the "San Luis Drain"). By 1975, an 82-mile segment of the Drain (Laguna Avenue in Fresno County to Kesterson Reservoir) and 120 miles of collector drains were completed. The first 1,280 acres of a planned 5,800-acre regulating reservoir complex was to be used for wetland habitat. When construction was interrupted in the mid-1970s because of federal budget constraints and environmental concerns, the Bureau decided to use Kesterson Reservoir to store and evaporate drainage water until the Drain to the Delta could be completed. Congress enacted PL 95-46 in 1977, authorizing $31 million to continue constructing the distribution and collection system for the San Luis Unit.

Between 1975 and 1979, the San Joaquin Valley Interagency Drainage Program (SJVIDP), an appointed task force of government and non-government members, conducted a comprehensive analysis of the drainage problem and the San Luis Unit Project (USBR, 1978). The SJVIDP was a joint effort of the Bureau, DWR, and the State Water Resources Control Board to formulate a Plan for agricultural drainage and salt management in the Valley. SJVIDP published a final report and first-stage environmental impact report recommending phased construction of a valley-wide drain between the bed of Kern Lake in the south and Suisun Bay near Chipps Island in the north (SJVIDP, 1979).

The Bureau used the interagency report to plan for completion of the Drain and initiated discussions with SWRCB to obtain a discharge permit. SWRCB also used the interagency report in guiding the Bureau's preparation of a permit application. The application was to contain 6 study plans and 13 other related items comprising a Report of Waste Discharge.

The Bureau completed the six study plans in 1983, but the Report was never completed. In 1983, deformities and deaths of aquatic birds were discovered at Kesterson. This was attributed to selenium toxicity (SJVDP, 1990); the finding significantly altered the perception of drainage water impacts and affected the approach to addressing drainage and related problems. Work on completion of the Drain has not yet resumed.

Post-Kesterson Drainage Management, San Joaquin Valley Drainage Program. In 1984 in response to the findings at Kesterson Reservoir, the San Joaquin Valley Drainage Program (SJVDP) was established to investigate drainage and drainage-related problems and to develop possible solutions (ibid). The SJVDP was a joint federal/State effort involving the U.S. Fish and Wildlife Service, U.S. Geological Survey, the Bureau, and California Departments of Fish and Game, and DWR. Figure 3 shows the five SJVDP study subareas. SJVDP initially conducted a preliminary investigation of all drainage management options, including out-of-valley drainage water disposal. In 1987, an SJVDP-commissioned report (Brown and Caldwell, 1987) presented possible areas for drainage water disposal, such as the Pacific Ocean. In reaction to that report, the Citizen’s Advisory Committee recommended to the SJVDP Policy Group that program efforts be focussed on in-valley solutions. SJVDP thereafter adopted the approach that agriculture should strive to correct, to the extent feasible, the drainage problem in-valley before resorting to out-of-valley disposal options.

The SJVDP developed *A Management Plan for Agricultural Subsurface Drainage and Related Problems on the Westside San Joaquin Valley*, also known as the Rainbow Report, to manage drainage problems from 1990 to 2040 (SJVDP, 1990). Although the 1990 Plan was based on managing the problems in-valley for several decades without exporting drainage water and salts to the ocean, it also stated that, "ultimately, it may become necessary to remove salt from the Valley" (page 1 of the 1990 Plan).

SJVDP investigated treatment technology, but did not recommend it as a drainage management component because of technology and cost uncertainties. SJVDP did recommend, however, continuing treatment technology research, demonstration projects, and continued monitoring to assess the progress and efficacy of various management measures. Key components of the SJVDP recommended plan were: source reduction, drainage reuse, land retirement, evaporation ponds, groundwater management, River discharge, water for protection of fish and wildlife, and institutional changes.

San Joaquin Valley Drainage Implementation Program. Federal and State agencies initiated the San Joaquin Valley Drainage Implementation Program (SJVDIP) in 1991 to pick up where SJVDP left off, following through on program recommendations (SJVDIP, 1991). Four federal agencies (USBR, USFWS, USGS, and Natural Resources Conservation Service) and four State agencies (DFA, DWR, DFG, and SWRCB) signed an MOU in December 1991. The agencies agreed to use SJVDP's 1990 Plan as the guide to correct the Valley's subsurface drainage problems. They agreed to work together to identify specific tasks and associated responsible parties, seek needed funding and authority, and set schedules to implement all components of the SJVDP 1990 Plan. Those signing the MOU recognized that the success of the program depended on local districts and irrigators carrying out effective drainage management measures. Because drainage is a regional problem, however, federal and State agencies needed to remain involved to coordinate efforts.

3. Overall Applicability of Each Option

Problem Statement

History is replete with examples of irrigation projects that ultimately failed because of salt accumulation and the inability to remove salt from soils and shallow groundwater. The classic historic example is Mesopotamia. Irrigation projects in the area that is presently southern Iraq created a very productive agricultural system beginning about five millenia ago. Copious quantities of water were available, contributing to seepage and a consequent rise in the water table. Initially, only a few fields were affected, but increases in salt-affected fields were recorded between 1200 and 1800 BC. Declining yields and a shift to cultivating more salt-tolerant crops paralleled increasing salinity. The southern part of the alluvial plane never recovered from the decline resulting from salinization. The story of Mesopotamia is ancient, yet the story of Mesopotamia (with minor variations) has been repeated for millennia in other lands and could be repeated in the western San Joaquin Valley.

Climatic conditions in the western San Joaquin Valley require importation of irrigation water for economic agricultural production. Dissolved salts in the irrigation water are simultaneously imported. Irrigation to achieve high yields is virtually impossible without some water percolating below the crop root zone. Indeed some deep percolation of irrigation water is required to leach salt that accumulates in the root zone soil. Water percolating below the root zone moves vertically downward through the unsaturated zone until it reaches the water table. After reaching the water table, water flows in the direction of hydraulic gradients, which might eventually carry it a considerable horizontal distance to a point where the hydraulic head is lower. Deep percolation may also cause the water table to rise directly underneath the field.

The fine textured alluvium in the western San Joaquin Valley is derived from sedimentary coastal range deposits containing significant quantities of soluble mineral salts and trace elements such as selenium, chromium, arsenic, boron, lead, mercury, cadmium, copper, and zinc. Most of the undesirable characteristics associated with western San Joaquin Valley soils are directly due to their origin from marine sedimentary parent materials of the Coast Ranges. Water that percolates below the root zone moves through these sedimentary materials, and dissolves salts and other chemicals.

As the water table approaches the land surface, drainage systems may be installed to keep the water table from encroaching into the crop root zone. Drainage waters typically have high concentrations of salts and various trace elements, with concentrations varying with location. The challenge is to properly reduce, reuse or dispose of these drainage waters. The salt in the drainage water impacts its reuse for irrigating agricultural crops, and the selenium in the water can negatively impact wildlife if discharged into wetlands or other water bodies, greatly decreasing its utility for creating wetland habitat.

Agricultural lands with a shallow water table ultimately must have a drainage system to lower the water table, remove salt, and maintain productivity. If it were not for selenium in the drainage water and wildlife impacts associated with it, an out-of-valley drain such as the partially constructed San Luis Drain likely would have been completed. Such a drain would have enabled drainage waters to be conveyed from the Valley and discharged directly into the Sacramento-San Joaquin Delta or Suisun Bay and flow to the Pacific Ocean. The presence of selenium in drainage water not only curtailed completion of the Drain, but also is the major obstacle towards finding alternative solutions.

Solution Approach

The eight Technical Committee reports (SJVDIP, 1999a-h) summarize the scientific information on individual management options that may address the problems associated with in-valley management of drainage, salinity and toxic trace elements in the western San Joaquin Valley. Economic considerations are contained in a separate report, "Economics of Salinity and Drainage Management: Regional Integrated Models" (Knapp, 1999). No single management option is adequate to solve all drainage related problems, and many options require interaction with other options for maximum benefits. The challenge is to identify the optimal mix of options. Because of variable conditions throughout the Valley, the optimal mix of management options will differ based upon location. Construction of a drainage canal with discharge into the Sacramento-San Joaquin Delta or Suisun Bay has never undergone full scientific inquiry, and is not evaluated in the present Activity Plan. Therefore, without scientific evaluation, the option to complete the out-of-valley drainage canal cannot be included in the present discussion that will be restricted to in-valley options.

A schematic presentation of the in-valley options is presented in Figure 4. The schematic presentation of options in Figure 4 does not show the surface and subsurface hydrologic system that provides the spatial connection between management options. Surface hydrology is visible and can be quantified. For example, the end-point of drainage water pumped to the surface can be traced by following its flow to an evaporation pond, a field for irrigation reuse, a ditch where it is diluted, etc. Subsurface hydrology is much more complex and has not been completely characterized at some locations. Nevertheless, subsurface hydrology provides the spatial connection between management options that affect subsurface flows. For example, deep percolation on one farm may travel some distance and result in drainage water on another farm. Therefore the consequent effects of management options can be completely evaluated only from a spatial viewpoint encompassing the interconnection of surface and subsurface hydrology. Because groundwater flow is relatively slow, the temporal effects of management must also be considered. For example, a change in management affecting the amount of deep percolation from an up-slope grower may not be reflected in the amount of drainage for a hydrologically-connected down-slope grower for several years.

Reducing Drainage Water Volume

Irrigation and drainage management, groundwater management, and land retirement (appearing on the left side of Figure 4) are three options to reduce the volume of drainage water requiring surface disposal. Each was the topic for a technical committee. Reduction in volume of applied irrigation water and discharged drainage water will be referred to as source reduction. Source reduction and groundwater management permit continued agricultural production, whereas land retirement converts land from agricultural production to other uses.

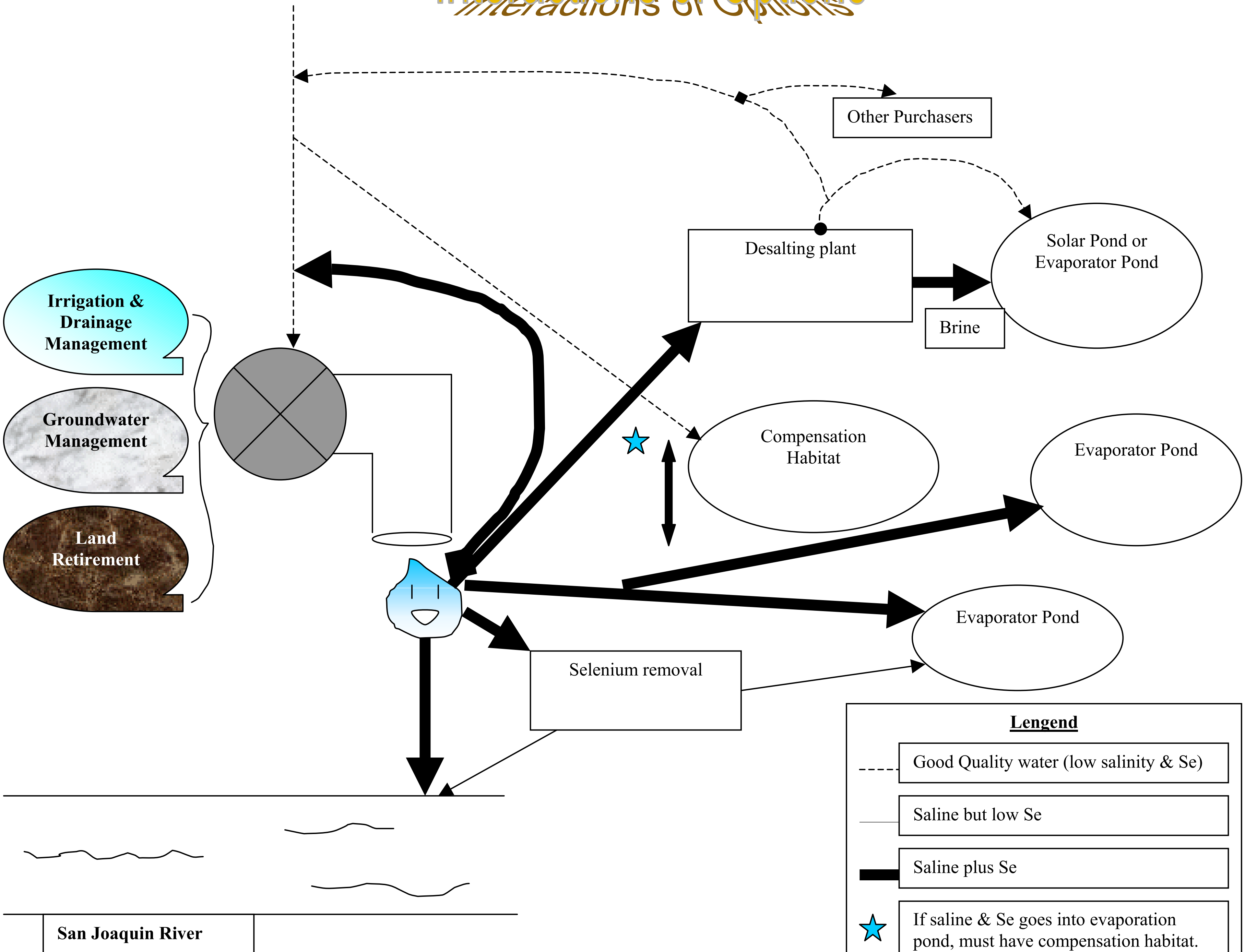
Irrigation and Drainage Management. Reduction of drainage volume by irrigation and drainage management is largely driven by three factors: 1) the ability to precisely control the rate of water infiltration into the soil, 2) the ability to apply water uniformly across a field, and 3) degree of drainage water reuse. The later is discussed under Drainage Reuse. The ability to control the rate of infiltration is necessary to achieve the goal of replenishing the soil water supply to maintain crop yield without applying excess water and increasing drainage volumes. Source reduction can be achieved by improving the scheduling of irrigation. One method involves using reference ET data provided by the California Irrigation Management Information System (CIMIS) weather stations, combined with appropriate crop coefficients (K_c). A plant's water usage varies during the growing season; therefore, the most accurate estimates of crop ET will be obtained by employing improved seasonal crop coefficients.

Irrigation systems can be broadly classified into pressurized irrigation systems and surface-applied gravity-flow systems. Pressurized systems are those in which water is delivered through a pipe and then discharged through various orifices such as a sprinkler head or drip emitter. In surface-applied systems, irrigation water is applied at one end of a field and flows across to the other side of the field, such as in a furrow irrigation system. Pressurized systems, such as sprinkler and drip, allow precise valve control on the rate of water applied during irrigation.

Non-uniform distribution of irrigation means that some parts of a field receive more water than other parts of a field. If irrigation were applied to achieve high yields on those portions of the field receiving the least water, the result would be an excess of irrigation water applied to other parts of the field with resultant large drainage volumes. On the other hand, if irrigation is designed to reduce drainage from the sections of the field receiving the most water, yields would be severely reduced on the sections of the field receiving the least water. Non-uniform irrigation requires a significant trade-off between achieving high yields and minimizing drainage volumes. Uniform distribution of irrigation water achieves both high yields and low drainage volumes.

The uniformity of water distribution is dependent upon the design and maintenance of the irrigation system. Surface applied systems provide the least control over both irrigation uniformity and the amount of irrigation. Two factors contribute to non-uniformity of surface irrigation systems. First water must flow across the field, and therefore it in contact with the soil longer at the head of a field than at the tail of a field. This is referred to as opportunity time non-uniformity. Second, the infiltration of the water depends on soil properties. Fields may have high soil variability with non-uniform infiltration rates. The amount of water that infiltrates the soil is dependent not only on how long the water is applied to the field, but also the soil infiltration rate.

Interactions of Options



Further, the uniformity of sprinkler systems is decreased by factors such as wind. Thus, the irrigator has limited control on the amount of water that infiltrates a given field.

Deep percolation resulting from furrow irrigation can be reduced by properly designing furrows with shorter lengths. Deep percolation can also be reduced by improving water delivery management, such as switching to surge-flow. Both of these overall techniques—better furrow design and better water delivery management—help to make the distribution of applied irrigation water more uniform. Deep percolation can be excessive during germination and growth of seedlings in furrowed fields. Water must be applied in sufficient quantity to wet the full length of the furrows, yet the young plants are not large enough to take up very much water. Switching to sprinkler irrigation can be helpful in reducing deep percolation in the first stage of crop growth. By using sprinklers, the irrigator can wet the soil sufficiently and uniformly, with lower application rates than with furrow irrigation.

Surface and subsurface drip irrigation, when well designed and managed, will substantially reduce deep percolation losses. However, drip systems typically are economical only when the crop is of relatively high value. With drip irrigation, a wetted zone forms around each emitter and salt tends to accumulate at the perimeter of this wetted area. Eventually, this salt must be leached from the soil.

Potentially, the relative opportunity for increased uniformity and control on the amount of applied irrigation water is in the order of furrow $<$ sprinkler $<$ micro-irrigation systems. The costs associated with each irrigation system are also in the same order. Constraints in converting to potentially higher performance irrigation systems are economics and crop suitability for pressurized irrigation systems. The major economic question is whether the increased costs involved in upgrading irrigation systems are offset by increased benefits. Many cost/benefit analyses only consider the effects of the irrigation system conversion on crop yield without consideration of the reduced costs associated with managing drainage volumes. If the benefits associated with reduced drainage volumes are not considered in the cost/benefit analysis, the results are biased towards the cheaper and less efficient irrigation systems.

Crop Use of Shallow Groundwater. The management option known as root-zone water extraction involves allowing deeper-rooted plants to satisfy part of their ET requirement by extracting water from a shallow water table. Promoting root extraction of groundwater may result in reduction of applied irrigation water and the volume of drainage water that must be collected and managed. Limitations include having a crop with roots deep enough to reach the groundwater table (such as cotton) and a crop tolerant of salinity present in the groundwater. Tress such as Eucalyptus have been used to lower shallow water table or intercept flow of shallow groundwater. Trees have been used for this purpose in a demonstration project at Red Rock Ranch in Fresno County.

Most drainage systems are designed with lateral drain lines discharging into a main line leading to a sump which is pumped. When the water table is higher than the drain line, water flows into the drain line until the water table has been reduced to the drain tile depth. Any irrigation that exceeds the water-holding recharge capacity of the root-zone soil increases deep percolation and groundwater recharge, thereby causing the water table to rise and initiate drain flows. The rate of water table drop is related to the spacing of the drainage lines and the hydraulic conductivity of the soil.

A control valve can be placed on the drain outlet, regulating drainage flows and retaining more water in the soil profile for later use by the crop. Drainage outlet control has the dual advantage of reducing drainage outflow, and also reducing the need for irrigation water. Water normally removed through the drainage system can be retained for crop use when of suitable water quality. The control valve could be temporarily opened to release drainage if the water table gets too high in the crop root zone and or to discharge water for salt reduction within the root zone.

A major impediment to implementing the drainage control option is the present design of drainage systems. Placing the control on the main line discharging into the sump, or controlling the pumping of water from the sump, is not adequate. Drainage laterals are progressively at higher elevations moving up the field. Controlling the water table elevation at the sump would have very little effect on water table control on laterals at higher elevations. Therefore, a system must be designed that can control each individual lateral. Comparatively little research has been devoted to drainage outlet control management. Both the engineering and management aspects require additional research before firm guidelines could be established for this practice. Drainage outlet control is important to increasing the utility of solar evaporators and discharge to the San Joaquin River, as will be discussed below.

Groundwater Management. High water tables and substantial drainage volumes are the direct result of an imbalance in regional groundwater budgets. Water is typically applied to the soil surface at a rate that exceeds the soil water-holding capacity and the carrying capacity of the groundwater system. Recharge rates exceed the groundwater system capacity to discharge via subsurface lateral flow and flow to wells. Water tables consequently rise until intersecting drains or the topographically lower portions of basins.

Regional groundwater budgets must be altered to reduce drainage volumes. Modeling studies show that this can be accomplished through a combination of reductions in groundwater recharge and increases in groundwater pumpage. Reductions in recharge can be accomplished by reducing deep percolation through source reduction, crop use of shallow groundwater, and land retirement. The notion in recent years that the increases in pumpage would have to come from the semi-confined aquifer or from new wells drilled specifically for water table management is incorrect. Regional groundwater models and basic hydrogeologic principles demonstrate that increased pumpage can occur in existing wells. Further, allocating a significant portion of that pumpage to wells tapping the sub-Corcoran confined aquifer can be quite effective for lowering the water table regionally. This occurs by inducing increased rates of downward leakage regionally across the Corcoran clay. Increased pumpage would have the benefit of providing increased water for irrigation and decreased demand for existing surface water supplies.

In view of regional modeling studies that elucidate groundwater system processes, the notion in recent years that the groundwater management option should be implemented locally or only as a short-term solution is no longer appropriate. It is now clear that if local or regional drainage volumes are to be significantly reduced, long-term regional groundwater management is necessary. This strategy alone would significantly alter the regional groundwater budget that ultimately controls water table elevations. Some local implementation of groundwater management can perhaps affect water table elevations locally, but the net impact of such a strategy would be negligible regionally.

In general, concentrations of both dissolved solids and trace elements decrease with depth in the semi-confined aquifer overlying the Corcoran clay layer. Better water quality is found in the confined aquifer system under the Corcoran clay layer. Pumping the better quality water from deeper wells causes a downward movement of the poorer quality water found at shallower depths. plants extract the water resulting in a high salt concentration in the water leaving the root zone. In practice, good water quality is extracted by pumping and replaced by poor quality water percolating below the root zone causing a gradual depletion of the good quality groundwater supply. Presently, groundwater pumping is increased during drought years when surface water supplies are limited. Exploiting the supply of good quality groundwater decreases the opportunity to reduce the impact of drought by increased pumping in future years.

Increasing the groundwater pumping rates would accelerate the ongoing, downward movement of poor quality groundwater. Because this process will occur even without increases in pumpage, it is not clear whether the relative water quality impacts would be significant. Groundwater quality at some, local supply wells would probably be impacted on a ~10-yr time scale rather than, say, a ~20-yr time scale. Regionally, however, the "life" of the aquifer in terms of groundwater quality would be on the order of a century or more.

Several state laws prohibit degradation of groundwater, with exceptions being made in rare instances where the degradation is deemed beneficial to the people of California. Proactively managing groundwater resulting in accelerated groundwater quality degradation would require such an exception, but would be consistent with the fact that groundwater quality degradation is already occurring under present pumping practices in the San Joaquin Valley.

Regional groundwater analyses indicate that increases in pumpage can significantly lower the water table without creating excessive risk of inducing land subsidence (i.e., without dropping confined aquifer water levels below historical lows).

Significant improvements in monitoring of groundwater quality, groundwater levels, pumpage, and subsidence are needed to support implementation of the groundwater management option in an adaptive framework. Even if a groundwater management option is not adopted, such information is necessary for basic stewardship of water resources in the basin.

In summary, opportunities in groundwater management include: (1) maintenance of agricultural productivity, (2) decreased demand for surface water supplies resulting from increased pumpage, and (3) decreased amount of drainage water requiring disposal. Constraints in groundwater management include: (1) reduction in the supply of good quality groundwater limiting future opportunities for conjunctive use, (2) imposition of the requirement of universal participation and regulatory compliance in regional management instead of voluntary action, (3) increased potential for accelerated degradation of groundwater, and (4) unsuitability of groundwater quality pumped from above the Corcoran clay layer for some uses.

Land Retirement. Land retirement eliminates most irrigation, and therefore implicitly ends the need for drainage on retired lands. The original purpose in including land retirement in the 1990 Management Plan was a means to isolate lands with relatively high concentrations of selenium in the soil and shallow groundwater. Other benefits of land retirement have since gained in importance. Water that would have been applied for irrigation becomes available for other uses. Retired land could become suitable as wildlife habitat for upland endangered species. The nature of the restored habitat is partially dependent on land management. A whole range of scenarios could be considered based on the type and level of adaptive land management and management costs.

As a voluntary program, lands most likely to be retired have very low agricultural economic return because of existing high water tables and salinized soil and water resources. The lands are typically located at the lower elevations near the trough of the Valley. Water tables would be expected to drop under lands not irrigated. However, depending on precipitation and lateral flows into the area, water tables could be maintained at a depth close enough to the surface that water would move by capillary action to the surface and evaporate. Upward water flow would carry salts and toxic elements such as selenium to the surface and deposit them through evaporation. This would lead to land with sparse vegetation, wind erosion, and poor quality and possibly toxic habitat. Therefore, one of the major questions related to the land retirement option is whether the water table would be deep enough to prevent salinization and selenification of the soil surface. Some retired lands could require ongoing management, such as pumping of groundwater, to prevent soil salinization caused by saline groundwater entering the site from below, adjacent, or up-slope areas. Otherwise, lands taken out of agricultural production could lose environmental quality and future value, including for wildlife habitat.

The socio-economic impact on local communities of the value of crops not grown must be counted as part of the cost of retiring a parcel of agricultural land. Substantial direct costs may be involved in the purchase of the land for retirement, and monitoring and management of the land after retirement. Restoration for wildlife habitat will incur additional costs.

A number of land management measures and alternative strategies to permanent land retirement and complete cessation of irrigation could achieve the same objectives of source reduction and reduced drainage volume, while minimizing or avoiding soil salinization and reduced plant growth. Alternative measures and strategies include:

- systematic implementation of rotational-, distributed-, or periodic-fallowing programs;
- pumping of groundwater for reuse as limited irrigation of winter crops to counter the upward transport of salt from shallow groundwater to the soil surface, while providing plant growth opportunities for both agricultural and upland wildlife habitat uses.

Summary. Each option to reduce the volume of drainage water has advantages and disadvantages. Groundwater management allows continued agricultural operation, but requires regional management and compliance in order to maintain a lowered water table. Groundwater resources would be used in lieu of surface water supplies, reducing the option for future conjunctive use. Reducing drainage volume by irrigation and/or drainage outlet control has the benefit of maintaining crop production while being technically feasible, but has economic considerations. Control of drainage outlets would require additional research to demonstrate utility, but the control would compliment discharge to solar evaporators or the San Joaquin River. Overall, irrigation systems which allow the greatest control are also the most expensive.

Land retirement does not allow continued agricultural productivity, but it does free surface water supplies for other uses, and reduce or eliminate the need to dispose of drainage water from retired land. The long-term consequences of land retirement depend upon what type of adaptive land management is adopted. One of the most critical factors affecting land retirement is whether the water table will be sufficiently deep to prevent the transport and accumulation of salts and trace elements to the surface affecting soil quality and creating an environmental hazard.

Any lateral water flow from up-slope growers to down-slope growers impacts the implementation of irrigation water source reduction or drainage outlet control. Up-slope growers who do not have a high water table have no financial incentive to reduce drainage flows by upgrading to more expensive irrigation systems. Drainage outlet control is not an option if they do not have a drainage system. Conversely, down-slope growers incur costs associated with the additional drainage contributed by up-slope farmers.

Drainage Water Treatment

Although source reduction, groundwater management, and land retirement provide an opportunity to reduce the amount of drainage water, some drainage water will still require reuse or disposal. One option is water treatment to improve the quality and thus utility. At present, reverse osmosis (RO) is the most promising technology for complete treatment of drainage water, i.e., removal of dissolved salts including selenium. Advances in membrane technology have increased the efficacy of RO treatment. The technology is available; implementation of RO treatments driven by economic considerations. The capital costs for constructing a RO treatment facility are estimated to be between $2-$3/gal/day of capacity. The higher investment would be required if extensive pretreatment of the water prior to RO were necessary. The operating costs are estimated to be between $150-$300/acre foot. RO is an energy intensive operation and the costs are greatly affected by energy costs. The stated capital and operating costs do not include the costs of collecting the drainage, delivering the treated water, or disposing of the waste brine.

A number of significant benefits could be associated with implementation of membrane treatment technologies such as RO treatment systems alone or in combination with other drainage management options. In the case of the imposition of more stringent regulations and prohibition of drainage discharge from the Grasslands Subarea to Mud Slough and the San Joaquin River, RO treatment offers an alternative to the discharge of drainage and could allow for the continuance of the present level of agricultural production. RO results in one useful product now in short supply in the San Joaquin Valley – pure water. The purified water could be sold to a municipality, possibly at a profit to the RO operator. The resultant brine could be used on halophytic crops appropriate for the salt concentration. The concentrated drainage could then be discharged into a solar evaporator resulting in salt desiccation and recovery. Although a commercial market for the salt is not available at the present time, if RO coupled with salt separation and disposal or utilization could be accomplished economically, the cycle would be closed and drainage would have a beneficial use. In the absence of a market for salt products, the brine or salts can be discharged into lined disposal facilities.

If the RO process could be made sufficiently feasible, it could be used to treat shallow groundwater that is currently too saline for general agricultural use. The pumping and treatment of shallow groundwater could help to reduce existing shallow groundwater levels, as well as create a new freshwater supply. Specifically, the RO process could be used to treat shallow groundwater under retired lands in the eventuality that rising shallow groundwater could be affecting soil quality and therefore wildlife habitat quality.

The two major obstacles to extensive RO technology implementation are the costs of operation and the current limitations on brine disposal. Purified water would have to be sold at a price greater than most agricultural operations could afford to offset the operational costs. Urban water users could come closer to affording the price for the purified water. Therefore, treatment of drainage water through RO becomes more feasible if water transfer through an open market is developed between the agricultural and the urban communities. Growers could use treated drainage water in lieu of surface water supplies, which could then be transferred to the urban sector.

Safe disposal of the brine could pose an environmental problem. The brine could be extremely concentrated in salts as well as selenium, depending upon the initial concentration of selenium in the drainage water and the degree of concentration achieved in the RO process. Solar ponds, and solar evaporators, or lined disposal facilities are potential brine disposal options. Feasibility planning for RO coupled with a disposal option should be conducted.

Solar Ponds. A solar pond is constructed by placing very concentrated saline water on the bottom of a basin, with less saline water at the surface. A density gradient is created with the densest water at the bottom and the least dense water at the top of the water column. This arrangement provides an opportunity to capture solar energy and convert it into electricity. Solar rays pass through the stratified, ponded water, heating and raising the temperature of the lower saline water. In ordinary ponds, warmer and lighter bottom water rises to the surface, displacing heavier, colder water above and causing convection currents. These currents rapidly disperse the heat throughout the pond, preventing any portion of it from reaching a high temperature. The dense saline water at the bottom of a solar pond can stabilize under solar heating, with cessation of convection currents and pond circulation. The bottom layer of hot brine, called the storage zone, is the system's energy accumulating component.

The stored heat must then be extracted from the lower layer of the pond for utilization. The water from the bottom layer can be removed from one side of the pond, passed through a heat exchanger, and the cooled water returned to the pond. With special care, the water from the lower level can be cycled without disturbing the established density gradient. Potentially, solar ponds allow the opportunity to produce energy as well as dispose of brine. Treatment of drainage water would provide a continual stream of brine. That would require continual expansion of solar ponds to accommodate the continual brine stream. The use of solar ponds for electric power generation has been extensively researched in Israel. A demonstration unit has been successfully operated at the Dead Sea for several years. However, the climatic conditions at the Dead Sea are considerably different from those in the San Joaquin Valley. The economic benefit of solar ponds is uncertain. Since selenium may be present in the pond brine, there is also a question about hazards to birds that might inhabit the pond.

Solar Evaporators. A solar evaporator is defined as an evaporation system where drainage water is not allowed to pond within the system. The flow of drainage water into the solar evaporator is regulated to equal or be less than the rate of evaporation. Two benefits associated with using solar evaporators are reduced wildlife impacts and facilitated salt harvesting. The major disadvantage is that the rate of discharge must match the rate of evaporation. Since both drainage flows and rates of evaporation vary with time, matching the two is difficult. However, with an efficient RO unit, the salt brine could be made very concentrated and therefore the volume of drainage water to be evaporated would be minimized. A control system on the drainage outlet (which was discussed under *Crop Use of Shallow Groundwater)* would be complementary to the use of solar evaporators. Drainage discharge could be timed to more closely accommodate the evaporation potential.

Treatment for Selenium Removal. Treatment of drainage water to remove only selenium would still leave very saline water requiring reuse or disposal. Nevertheless, the removal of selenium would increase the options for reusing or disposing of the drainage water without biological impact.

Chemical reduction to treat drainage water for selenium removal has been investigated. Zero-valent iron filings can be used to reduce selenium. However, tests have indicated that the beds tend to become cemented with precipitate. Ferrous hydroxides are also possible, but generally have a slow rate of reaction. In both cases, nitrate concentration in the water interferes with the removal process. Also, each system would require a reactor and while the economics have not been evaluated, it is probable that the systems would be overly expensive.

Several laboratory investigations have demonstrated that bacteria can effectively reduce selenium. However, bacterial reduction has not been adequately demonstrated on a field scale operational level. Large reactors have not been tested, and again, the economics are not well identified.

The selenium concentration in water can be reduced in open systems. For example, an algal-bacterial selenium removal system consisting of a series of specially designed ponds has been tested. The concept of this process is to grow micro-algae to use nitrate, and then utilize the naturally settled algal biomass as a carbon source for native bacteria. The bacteria in the absence of oxygen reduce the remaining nitrate to nitrogen gas, and reduce selenate to insoluble selenium. The insoluble selenium is then removed from the water by sedimentation in deep ponds and as needed, by dissolved air floatation and sand filtration. This process in undergoing continued evaluation.

Flowing water through wetlands has been demonstrated to reduce selenium concentrations in water. This system consists of substrate containing organic detrital matter and actively growing plants, all in a flow-through system of ponds. Removal of selenium occurs by several mechanisms, including reduction of inorganic selenium to elemental selenium, adsorption of selenite to the charged surfaces of minerals and organic matter, plant uptake, and microbial volatilization, plus some inadvertent seepage losses. A field experiment is being conducted to investigate the effectiveness of a wetland flow through system for selenium removal. The research is evaluating the effectiveness of various types of vegetation and water retention times on selenium removal. More importantly, the research is trying to identify and quantify the fate of the selenium. The selenium removed by water may be volatilized, accumulated in the sediment, or incorporated in the plant tissue. A wetland flow through system is anticipated to reduce the selenium concentration in the water, but not to completely remove it. A positive feature of the wetland flow through system is that it may provide a relatively inexpensive means to reduce the selenium load in drainage water. The extent of selenium removal by a flow-through wetland system varies with hydraulic residence time and with seasonal changes in temperature and growth rates of plants in the wetland. The best removal rates achieved so far are at TLDD's wetland treatment system, where input concentrations of 15 to 20 ppb selenium have been reduced to 4 ppb in some cells.

One drawback of an open system for selenium removal is the potential for bird exposure. Thus, the treatment process is not 100% ecologically safe. Netting or waterfowl hazing may be necessary to prevent wildlife use of the wetlands. One major consideration is the trade-off between potential increased waterfowl impact from the treatment process, contrasted with the potential reduced waterfowl impact associated with using the drainage waters after treatment to reduce selenium. Reduction of selenium from the drainage water prior to discharge into an evaporation pond through use of the flow-through wetland treatment process, may contribute to an overall reduction in wildlife hazard relative to the hazard associated with pond discharge without the treatment process.

From an economic point of view, treatment to reduce or remove selenium allows it to be disposed of with less impact to wildlife. However, in contrast to the purified water resulting from the RO process, the market value of biologically treated water is not greatly enhanced because of the remaining salt content. Therefore, the added value of the water after treatment cannot be used to offset the cost for the treatment.

Evaporation Ponds

One means of disposing of drainage water is to set aside a portion of land to create a basin for ponding water for evaporation. Except for the limited opportunity to discharge drainage into the San Joaquin River, evaporation ponds in the Tulare Subarea and a few solar evaporators elsewhere are the only current means of isolating salt from productive agricultural lands. This option can be severely affected by the presence of selenium, which can impact wildlife using the evaporation ponds. Waterborne and sediment selenium within evaporation ponds bio-accumulates into the aquatic food chain by bio-concentration and bio-magnification mechanisms. The extent of bio-accumulation depends on the route of exposure (e.g., diet, water, or sediment) and chemical form of selenium. Some previously operational evaporation ponds have shut down, and are subject to closure and post-closure maintenance plans, because of regulatory criteria and costs associated with selenium management.

The future utilization of evaporation ponds for drainage water disposal is dependent on practices to eliminate or minimize bird impacts. In the Tulare Lake Basin**,** a variety of waterfowl and shorebirds seasonally inhabit or utilize evaporation ponds for resting, foraging, and nesting. Waterfowl may be impacted adversely from exposure and bio-accumulation of selenium through the food chain. Adverse impacts may range from impaired health and condition of adult birds, reduced hatchability of eggs, and embryonic deformities. Although species–specific differences exist among waterfowl, the focus has been mainly on American avocet and black-necked stilt. A number of complex interacting environmental and biological factors need to be taken into account to assess the potential adverse effects of selenium to wildlife.

Ultimately, the controlling factor in evaporation pond management will be the nature of regulatory requirements. Presently, Waste Discharge Requirements (WDR) for drain water disposal in evaporation ponds are based on the design and management of the ponds, as well as on site-specific mitigation. WDR's may also specify that compensation habitat or alternative habitat is provided. Compensation habitat is a waterfowl resting, feeding, and nesting area built outside the functional landscape of the evaporation pond, to provide breeding habitat in the presence of low selenium water. Such habitat has been constructed at TLDD. Alternative habitat is a waterfowl area built within the functional landscape of an evaporation pond, to provide year-round habitat to dilute the diet of birds with respect to selenium. Such a habitat has been constructed at Westlake Farms. WDR's usually specify one or more protocols for assessing the effects of the pond on waterfowl. Such protocols typically are based on egg selenium content and/or waterborne concentrations (current WDR for evaporation ponds having elevated selenium require that bird eggs are sampled each year, for measurement of selenium content). The WDR would identify a number of facility designs and operational parameters which are intended to reduce and avoid adverse impacts of evaporation basin on wildlife. In addition, the WDR may specify wetland habitat to compensate for unavoidable impacts thereby reducing the overall effect of the proposed basin operations to less than significant levels, as defined by the California Environmental Quality Act (CEQA).

Redesign and maintenance of evaporation ponds to reduce impacts to wildlife may include a minimum water depth of 2 feet, steepening levee slopes, reducing vegetative cover, removal of windbreaks, disease surveillance and control programs, invertebrate sampling, and bird hazing. All of these measures contribute to decreased use of evaporation ponds by birds. Methods that cause disruption of the selenium food chain, such as the commercial production and harvesting brine shrimp within evaporation ponds, are presently being developed and implemented. Reduction in selenium concentration in drainage water before discharge into ponds, through biological treatment methods such as flow-through wetlands, can reduce the hazard to birds. However, none of these practices provides an absolutely safe bird habitat without some potential impact.

Results of biological monitoring at evaporation ponds in the Tulare Lake Basin have shown substantial reductions in the numbers of nesting waterfowl, particularly American avocet and black-necked stilts, after modifications have been implemented. The results of monitoring have also shown that the numbers of stilts and avocets successfully nesting at compensation habitats is substantially higher than originally expected. Monitoring is continuing to refine the performance of compensation habitats and to address questions such as:

- the use of saline water with low-selenium concentrations as a water supply for wetlands,
- performance under drought conditions,
- alternative wetland habitat design and operations,
- the relationship between waterfowl production on compensation wetlands relative to the mitigation requirements to reduce unavoidable evaporation basin impacts to less-than-significant levels,
- the function of alternative habitats for reducing selenium dietary loads,
- and the contribution of compensation habitat production to the adult waterfowl population and the associated assessment of net environmental benefits.

Monitoring of waterfowl nesting, abundance, nest fate, egg selenium, and embryonic conditions within operating evaporation basins and compensation and/or alternative habitat will continue in compliance with the requirements.

Policies that allow for compensation habitats to offset associated impacts of ponds will enhance the future utility of evaporation ponds. Studies on compensation habitat during recent years have shown that:

- compensation wetland habitat can be designed and operated successfully to support high densities of nesting wild birds;
- nesting success has been shown to be high at several compensation habitats where predatory exclusion has been effective;
- a carefully designed vegetation control program can contribute to the long term success of the mitigation site; and
- relatively larger numbers of young waterfowl are produced at compensation wetland habitats when compared to current estimates of waterfowl nesting at several of the evaporation basins.

Compensation habitat does require setting aside land and good quality water that might otherwise be used for agricultural production. However, this may be a modest cost if it allows productive agriculture to proceed on acreage that requires drainage.

Protocols (Hanson 1993, 1995; USFWS 1995a) are available to estimate unavoidable adverse impacts on American avocet and black-necked stilts, and the acreage of uncontaminated compensation wetland to mitigate unavoidable losses as required by CEQA. A second protocol (USFWS 1995b) has also been proposed for alternative wetland habitats to provide foraging for targeted waterfowl so that selenium dosing from contaminated basins could be reduced. These protocols to calculate compensation and alternative habitats utilizing site-specific information on waterborne selenium concentrations, abundance of nesting stilts and avocets at the evaporation basin, and the anticipated density (number per acre) of stilts and avocets at a managed wetland site. Presently available scientific-based risk analyses indicate that such analyses require site- and species-specific appraisals. Although selenium is the principal constituent of concern, others such as salt and boron are of concern, too. Other factors such as predation, flooding of nests, entrapment in phosphate foams along shorelines, diseases such as avian botulism, and levee maintenance and other disturbances must also be evaluated as separate risk analysis and risk management.

During the operation of an evaporation pond, salts are concentrated as a result of evaporation. Those salts eventually must be harvested and utilized or isolated from the environment. One farm in Kern County has converted an evaporation pond to a solar evaporator to minimize wildlife impacts by concentrating the salts into crystals through evaporation (Vashek Cervinka, personal communication, 1999).

Drainage Reuse

Drainage waters can be reused for irrigation of salt-tolerant crops. Integrated on farm drainage management (IFDM) systems have been designed and put into operation in one 640-acre farm in the San Joaquin Valley. IFDM systems sequentially reuse drainage water on increasingly salt tolerant or halophytic crops to concentrate and decrease the volume of drainage water. Ultimately, the remaining drainage water is discharged to solar evaporators where the water is evaporated and the salt deposited. Opportunities could be developed for beneficial use of the harvested salt. Implicit in this system is the expectation that water percolating below the root zone is captured in the drainage system to be passed on to the next, more salt tolerant crop. Unless the drain lines are closely spaced, some of the deep percolate may not be captured in the lines immediately below the field. Depending upon the local hydrology and the location of the fields, some of the drainage water may migrate to other areas, and/or the drainage systems may capture considerable water originating from more distant areas.

High salt concentration, and in some cases boron concentration, limits the utility of drainage water for crop production. Some crops are tolerant to both salinity and boron; other crops are tolerant to salinity but not tolerant to boron, or vice versa. Thus crop tolerance to both salinity and boron relative to the concentrations in the drainage water is important in choosing appropriate crops. Reusing drainage waters for irrigation is putting the salt back into the system. Thus, this practice creates a continual accumulation of salts with long-term limitations. Ultimately, salts must be removed from agricultural lands to maintain productivity.

Although some crops are tolerant to salinity, all plants have a limit to salt tolerance, and yields are decreased if the salinity level in the soil and water exceeds the tolerance level. Therefore, leaching accumulated salt from the root zone soil by the annual application of excess irrigation water is required for all crops. Indeed, the required leaching fraction to maintain high crop yields may be large if the salinity of the irrigation water is high, even if the crop is salt tolerant.

Destruction of soil physical properties creating crusting, which restricts germination and decreases infiltration rates, is a hazard associated with using saline irrigation waters. The use of amendments such as gypsum can mitigate the negative impact of saline waters on soil physical properties. However, this is a management practice that imposes an additional cost and must be implemented to prevent loss of soil quality.

There may be a temptation to use poorer quality land for reuse of drainage water. This may create problems, particularly if a fairly high leaching fraction is required. If the soil water transmission properties are not high, large leaching fractions cannot be achieved, and the soil profile may remain excessively wet leading to oxygen depletion and a negative impact on plant growth. The combination of high salinity and low oxygen supply could greatly reduce yields.

In summary, drainage waters can be reused for irrigating salt tolerant crops. After evaluation of soil and water quality on a given farm, the decision to implement a reuse system is largely one of economic considerations. If a farm has no outlet for drainage water, assigning part of the property to utilize the drainage water, or implementing an IFDM system to ultimately discharge salt into a solar evaporator, may be economically feasible. The economically optimal solution would be derived from comparing the costs associated with source reduction such as crop use of shallow groundwater, drain water treatment, and drainage reuse. Included in the cost evaluation would be the economic return from the production of higher value less salt tolerant crops on soils leached of salt with newly installed drainage systems.

Discharge to the San Joaquin River

The Grasslands area has the opportunity to discharge some drainage water into the San Joaquin River. The amount of discharge is constrained by the requirement to meet water-quality objectives for the River, and to comply with load limit stipulations in the Grassland Bypass Project. The opportunity to discharge salts and selenium on an annual basis, without violating the water-quality objectives would be increased if the discharge could be timed to match the assimilative capacity of the River. The assimilative capacity varies seasonally because of precipitation and water release to the River. Matching release to the assimilative capacity has commonly been referred to as real-time management. Real-time management is facilitated by the opportunity to control the time and amount of drainage water released. This condition operationally requires the storage of drainage water from times when the drainage water exceeds the assimilative capacity to times when the assimilative capacity of the river is higher. Some storage might be accommodated within the soil profile if a drainage outlet control was in practice. This storage capacity is constrained by the requirement that the water table cannot be maintained too high in the root zone for an extended period of time. The construction of holding ponds provides another storage option. The main disadvantage of holding ponds is the potential hazard to wildlife using the ponds and being exposed to selenium toxicity.

In evaluating the consequences of discharging drainage water into the San Joaquin River, ecotoxicity of selenium compounds probably constitutes the most complex issue. The large gaps in knowledge have their roots in the extensive biogeochemical transformation and bioaccumulation of selenium. These research gaps were addressed in the 1999 “Peer Consultation Workshop on Selenium Aquatic Toxicity and Biocumulation” held by the U.S. EPA. The consensus opinion from the nine-member panel was that waterborne selenium concentration is not always a reliable indicator of selenium adverse effects on the aquatic top predators. This is because selenium exposure and effects in top predators (the major concern for selenium contamination) is mainly mediated through diets, i.e. the food chain organisms in which biotransformation and bioaccumulation occur. The consensus opinion emphasizes that the sediment and its resident food-chain organisms are major sinks for selenium bioaccumulation and biotransformation. Since these biogeochemical processes are very complex, they may be highly variable from site to site, leaving the need to address selenium impact on a site-by-site basis.

Our present knowledge of these processes is inadequate to allow an extrapolation from waterborne selenium concentrations to selenium impact on top predator on a site-specific basis. Nevertheless, such extrapolation is needed for setting appropriate water quality criteria for different site conditions. For sustainable protection of water quality, research is also needed to assess the biogeochemical assimilatory capacity of a given system with respect to biological or ecological impacts. Such impacts are the sole reason of concern over the trace elements such as selenium.

Salt Utilization

Major constraints in managing drainage water as stated in this report are the salinity effects on plant growth and the selenium toxicity to wildlife. High concentrations of salt are harmful to most plants and therefore salt levels in soil and water must be maintained within a certain range in order for productive agriculture to continue. Selenium can be toxic to wildlife, and wildlife exposure to selenium in agricultural drainage must be minimized. However, both salt and selenium have essential and established beneficial uses in industry, and for selenium, an essential nutrient in animal nutrition. Many areas of the world, including parts of California, suffer from a deficiency of selenium. Problems associated with salt and selenium then become ones of separation and distribution, not disposal. An evaluation of these elements as resources rather than pollutants is therefore justified.

The salt composition of drain water differs from that of seawater. Whereas seawater contains primarily sodium-chloride salt, drain water from the westside San Joaquin Valley typically contains sodium-sulfate salt. When drain water is concentrated by evaporation, the dominant minerals that precipitate are thenardite (sodium sulfate), halite (sodium chloride), gypsum (hydrated calcium sulfate), and calcite (calcium carbonate). The drain water also contains several trace elements of concern: selenium, arsenic, boron, and molybdenum. During the evaporation process, those elements will associate with, or become incorporated into, the precipitated mineral salts. Such contamination of the salt minerals may have positive or negative implications, depending on the intended use of the salt.

The commercial utilization of sodium sulfate includes dying of textiles, glass making, glazing and other industrial uses. All of these utilization options and others have been evaluated in the Salt Utilization Technical Committee Report. For certain commercial and industrial uses, salt must first be purified. For example, in the sodium-sulfate industry, purity exceeding 90% may be required. The U.S. market for sodium sulfate is about 1.5 million tons per year. However, as of 1989, the combined annual deposition of salt in evaporation ponds in the San Joaquin Valley was an estimated 0.8 million tons per year. The harvesting and marketing of that much sodium sulfate could drive down the price, possibly to levels so low that it would become uneconomical to harvest the salt. Transportation must also be considered in planning to utilize San Joaquin Valley salt. The cost of freighting the harvested material to a salt refinery or other market must be low enough to provide a profit.

Collection of water in solar evaporators facilitates the harvesting of salt. Thus, the feasibility of using solar evaporators, as previously discussed, is relevant to the goal of salt utilization. Indeed, if significant commercial markets were established for the utilization of the salts, it would provide an economic incentive to work towards the utility of solar evaporators.

Considering that 2-3 million tons of salt influx per year by irrigation water (in addition to significant amounts of salt mobilized from soils as a result of irrigation) needs to be disposed of to maintain salt balance in the Valley, even an optimistic estimate of the amount that could be commercially marketed would represent a small percentage of the total salts to be disposed. Active pursuit for commercial utilization of the salts and selenium is justified, and it will require all the other options for separating the salts from productive agricultural fields, however the salt utilization approach should not negate pursuit of other salt disposal options such as disposal in lined storage facilities or ocean disposal.

Conclusions

All of the options investigated by the Technical Committees and reviewed above can serve a useful role for developing in-valley drainage management strategies. However, except for what can be discharged into the San Joaquin River, evaporation ponds and solar evaporators, in possible combination with reverse osmosis treatment systems, are the only options for long-term separation of salts from the soils of agricultural lands. Various practices can be implemented to decrease the volumes of water requiring ultimate disposal into evaporation systems. However, all options other than discharge and separation in evaporation systems, maintain salinity in agricultural lands with long-term consequences. For example, blending drainage waters with good quality surface waters can be used for irrigation. However, in the absence of adequate leaching of salt from the root zone and salt removal, this practice will contribute to the continual salinization process, with its resultant long-term negative impacts on agricultural productivity.

Since evaporation systems serve as the only repository for salts that isolates them from productive agricultural fields, regulations on the operation of evaporation ponds will serve a pivotal role in determining the long-range agricultural productivity in the western San Joaquin Valley. The primary problem with evaporation ponds is potential selenium toxicity to waterfowl. Several steps can be taken to reduce the hazard to birds. Examples include design and management of ponds to reduce their attractiveness to birds, bird hazing, various approaches to disrupting the selenium food chain, reduction of selenium concentration in the water by flowing it through constructed wetlands prior to discharge into evaporation ponds, and other methods. A combination of these steps can be taken to greatly reduce negative impacts on birds, but it would be virtually impossible to design a system to be completely bird safe. To reduce wildlife impacts when selenium concentration is above 50 ppb, the 1990 Plan recommended accelerated rate evaporation pond, where water would be pumped and sprayed at an elevation above ground for enhanced evaporation of drainage water. This conceptual project has not been tested. However, a solar evaporator that is a modified form of accelerated rate evaporation pond has been tested in the Valley. In a solar evaporator drainage water is discharged to the pond at a rate equal to daily evaporation, thus no ponding occurs. Conversion of evaporation pond to a solar evaporator may present an option to reduce wildlife impacts. A cost and benefit analysis of operation of an evaporation pond and its mitigation habitat requirements in comparison to operation of a solar evaporator and associated drainage reuse system merits further study.

Studies on compensation habitat during recent years have shown that they can be designed and operated successfully to support high densities of nesting waterfowl. A policy driven by the goal of having high bird populations with the opportunity to have some bird impacts which are compensated for, increases the opportunity to use a combination of management options to sustain high agricultural productivity in the Valley.

4. Economic Analysis- A Framework

Introduction

The 1990 Plan (SJVDP 1990) identified a range of management options for salinity and drainage problems in the San Joaquin Valley. Corollary to that effort was development of the Westside Agricultural Drainage Economic (WADE) model that is an economic-hydrologic model of the westside drainage problem area. The model can be used to simulate a baseline case of no drainage regulation/policy, and to simulate the effects of various drainage policies such as an emissions charge. The former is useful for identifying what might happen if no action is taken, as well as serving as a base of comparison for the policy runs. The policy runs provide quantitative information to decision-makers about alternate levels at which to carry out possible regulatory actions.

The economic analysis presented here focuses on a conceptual overview of salinity and drainage management from the perspective of environmental economics. A review of the formal economics modeling efforts that have been carried out since SJVDP (1990) and development of the WADE model is presented in the Economic of Salinity and Drainage Management: Regional Integrated Models (Knapp, 1999).

This section outlines a conceptual framework for salinity and drainage management based on the environmental economics literature. A simplified setting is considered to clarify the basic ideas. The focus is on reducing net deep percolation flows.

Why Drainage Management? Externalities and Public Goods

From an economic point of view, the problem is due to externalities and the common property nature of the affected resource systems. When deep percolation or drainage flows are generated they may cause damages to the emitters as well as to other growers and society at large. These physical effects of one producer's actions on others which take place outside the market system are termed externalities. Growers clearly have an incentive to consider the impacts of their actions on themselves, but do not have an economic incentive to consider the effects of their deep percolation/drainage flows on others. Thus from a societal point of view, excess deep percolation emissions are likely and there is insufficient incentive to take remedial actions. As a result, some sort of collective action is necessary, either within or among existing water and drainage districts or at the county, state, or federal levels, and such action takes the form of some type of regulation on the generation and/or treatment and ultimate disposal of the residual emissions.

Pollution control in general and salinity and drainage management in particular can also be viewed as a public good. A public good is a good or service for which many can receive benefits without compromising others ability to receive the same benefits, and for which it is impossible to exclude others from consuming. (Classic examples are national defense and lighthouses.) Suppose now that we imagine reducing salinity and selenium concentrations in the San Joaquin River. Then all users of water in that system are able to enjoy the benefits of that cleanup without compromising others ability to do so, and it would also not be generally possible to exclude someone from receiving those benefits even if they were unwilling to pay for them. The implication is that users would not be individually willing to carry out possible control measures (e.g. a treatment process for flows entering the river), since they could receive the benefits for free if someone else carried them out, or they may be unable to collect from others if they did carry out the process. This is known as the "freerider" effect. Because of the free-rider effect, public goods and services are generally provided by the public sector as the name suggests.

As noted at the outset, one advantage of viewing the problem in this way is that it provides a formal basis for deciding when governmental or collective action is or is not justified in remedying some apparent problem. In the salinity and drainage case, of course, there are strong *a priori* reasons for expecting collective action to be necessary to solve the problem and prevent future occurrences. Another advantage of this approach is that it opens up a wider spectrum of possibilities for regulatory action. Classic U.S. environmental policy relies heavily on so-called command and control policies whereby regulators specify in detail what set of actions can and can't be done. If we view the problem as externalities, then the issue becomes one of providing correct incentives to individual producers to account for external costs (and benefits) of their actions. In this way, they would be free to decide on the best course of action while still accounting for the effects on others. Alternately, the problem can be viewed as one of a lack of markets for drainage flows, thereby suggesting another possible remedy that is to effectively create one.

Economically Efficient Management

Determining an appropriate salinity and drainage Management Plan for a region involves at least three sorts of issues:

a. What is the best mix of management strategies to achieve a given level of drainage reductions?
b. What is the appropriate distribution of pollution control burden across producers?
c. What is the best overall level of drainage reduction to be achieved in the region?

These questions are addressed here from the viewpoint of economic efficiency that in this context means maximizing net benefits to the region as a whole. Equity issues are not specifically considered at this point; these re-enter the picture through the choice of policy and regulatory instruments. Also it needs to be re-emphasized that these questions are being addressed in the simplest possible setting to clarify concepts; actual empirical studies will considerably expand upon and generalize this framework.

Following microeconomic analysis, we first consider an individual producer (the farm), and then aggregrate to consider management at the regional level. At the farm level, there are several general strategies available for solving drainage problems. For the sake of illustration we consider just three: source control, reuse, and disposal. In general there are a number of different options for achieving a given level of drainage reduction for each strategy. For example, source control could be achieved by moisture-stressing, new irrigation systems, crop switching and so on. For each strategy one finds the cost-minimizing set of options for achieving alternate levels of drainage reduction. This then determines functions for each strategy showing the cost of achieving alternate levels of drainage reduction with that strategy.

Figure 5(a) illustrates hypothetical marginal cost curves for each of the three strategies, where marginal costs are the derivative of the cost functions; they can be interpreted as the additional cost of achieving one additional unit of drainage reduction. As illustrated, the curves slope in an upward direction. This is both intuitive and realistic; it says that the cost of reducing additional units of drainage water becomes increasingly difficult and expensive the more one tries to reduce with a given strategy. Also, in Figure 5(a), D represents a desired level of total reduction in drainage emissions at the farm level. (The specific choice of D will be addressed later; for now we just take it as given.) Note that this is a reduction of emissions below current levels, not the final ending level of emissions.

A reasonable goal is to achieve any desired target level of reductions (say D in the figure) at the least-cost to both the farm and society. For least-cost pollution control, the burden of pollution control (drainage reduction in this case) should be allocated so as to equalize the marginal costs of control across all strategies. The reason for this is quite simple: if marginal costs are not equalized, then it is always possible to re-allocate the burden from the high-cost source to the low-cost source, thereby still meeting the target while lowering overall costs. To get an aggregate marginal control cost curve, we then horizontally sum the individual marginal cost curves. This means that for each price (marginal cost), we add up the individual quantities to get a total quantity. This results in a curve such as S in the figure. This curve shows the aggregate marginal cost of achieving alternate total levels of drainage reduction on an individual farm, given that the burden is allocated across alternate strategies (source control, reuse, etc.) in a least-cost fashion. It can also be interpreted as the “supply” of drainage reduction that would be forthcoming from growers at various “prices” for drainage reduction.

To complete the problem at the farm level, we can now combine the D and S curves. The least-cost way of achieving the designated target level of emission reductions is determined by the intersection of these two curves. This intersection determines an effective “price” or “shadow value” for drainage emissions. This can be interpreted as the value to the farm of each unit of drainage emissions achieved by the individual strategies. For least-cost control at the farm level, each strategy is pursued to the point where its marginal cost equals the price or shadow value of drainage emissions. As illustrated in the figure, this results in source control at level x^s, reuse at level x^r, and disposal at level of x^d.

Having identified the optimal decisions and marginal cost of drainage reduction at the farm level for a given total level of reduction, we can now consider the regional level. In figure 5(b) we suppose there are three producers in the region with individual marginal cost curves for drainage reduction as depicted. These are the S curves from figure 5(a); they differ reflecting that individual producers likely have differing opportunities and costs for drainage reduction. In this instance, producer 1 finds it the most difficult to reduce drainage flows while producer 3 finds it the easiest. For exactly the same reason as before, to achieve drainage control in the region at least-cost, we want to equalize the marginal costs of control across all three producers. This implies that the regional aggregrate marginal cost function is again the horizontal summation of the individual marginal cost curves. This is labeled as S^{reg} in the figure and can be interpreted as the regional cost of meeting various drainage reduction goals assuming least-allocation of burden among producers, and that producers are minimizing the costs of achieving their individual targets.

In figure 5(b), D^{reg} represents the "demand" for desired level of total reductions in net deep percolation flows to the aquifer. More precisely, this is the marginal benefits to society from achieving lower levels of drainage emissions. Note that this curve slopes downward and to the right. This is again intuitive and quite reasonable. Low levels of drainage reduction correspond to low levels of environmental quality, thus a 1 unit increase in drainage reduction could realize a relatively high gain to society. On the other hand, large levels of drainage reductions correspond to high levels of environmental quality with a pristine environment in the case of 100% control/zero emissions. Since organisms can likely tolerate at least some levels of emissions, then the last few units of control likely bring relatively small marginal benefits to society.

Maximum social net benefits from drainage reduction (economic efficiency) is achieved where the regional aggregate marginal cost S^{reg} cuts the desired reduction level D^{reg}. At this level marginal control costs just equal marginal benefits from control; this means that the value of an additional unit of drainage reduction is just equal to the cost of achieving that unit. As before, the intersection of these two curves effectively determines a "drainage price" or "shadow value" for drainage reductions denoted as P. With this price, we can then read off the desired levels of drainage reduction for each producer. For example, in the figure producer 1 would reduce to the level of x^1, producer 2 to the level of x^2 , and producer 3 to the level of x^3. This represents an allocation of the control burden across producers, which achieves the overall desired level of total reductions at the least cost to the region. Finally, to complete problem we go back to figure 5(a) for an individual farm. We could specify either the reduction to be achieved on the farm (x) or the drainage "price" (p). Either way, the producer then chooses the mix of strategies to minimize costs, resulting in source control at level x^s, reuse at level x^r, and disposal at level of x^d as previously discussed. Overall, this procedure results in a strategy mix at given locations, an allocation of the control burden across space, and an overall level of pollution control that maximizes social net benefits, hence achieving economic efficiency.

While substantial effort by environmental economists has gone into estimation and estimation methods for the marginal benefits of pollution control [D^{reg} in figure 5(b)], this relation is generally considered much more difficult to obtain - and much more tenuous - than the marginal cost curves. As a practical matter, therefore, many studies in environmental economics generally as well as salinity and drainage specifically, often take as given the level of environmental quality to be achieved, i.e. a vertical D^{reg} in the figure. Presumably this is set based on scientific considerations. The analytical goal in this instance is to achieve this overall target at least cost which is done exactly as in the more general case.

Conclusions

Several conclusions flow from this analysis:

- Reducing drainage flows is likely to involve a combination of strategies; its highly unlikely that any one strategy alone will either solve the problem, or, even more likely, be the least-cost way of achieving the end result.

- The optimal level of each strategy to be achieved depends on the cost and availability of other alternatives. For example, if a new irrigation technology were to be developed, that could shift the source control marginal cost function to the right (increased control for the same marginal cost). This would then shift the aggregate marginal cost curve S to the right, thereby lowering the "price" of drainage water and hence the desired level of reuse and disposal. Thus, at least in theory, the desired level of each strategy should be determined simultaneously with that of the other strategies.

- Figure 5 also illustrates the regional nature of the problem. Whether or not reuse or another strategy should be practiced on a given farm depends on the "price" of drainage flows, and that "price" is determined by the costs, opportunities, and actions of all farming operations in the region. Micro-level data and analysis is needed to formulate the regional problem, but solving the regional problem is necessary to generate relevant "prices" for then determining what micro-level actions are desirable.

Recent economic studies based on computer modeling techniques are reviewed in Knapp (1999). Conclusions from these studies are as follows:

- The results point in the direction of irrigation system uniformity as being the prime candidate for source control strategies. The various analyses appear to find relatively little crop-switching in the least-cost solutions, nor do the analyses suggest that land retirement/fallowing is a particularly appealing strategy, on average, however the studies do not rule out the possibility of land retirement in terms of local “hot spots”. Put another way, the existing empirical studies do not support land retirement as a cost-effective means of drainage reduction in general or on average. Rather, land retirement would need to be justified in terms of the higher moments of the problem; this is still an open (and likely) possibility in terms of formal economic analysis.

- The results also suggest that significant levels of drainage reduction can be achieved at fairly low costs in terms of lost net benefits from agricultural production; however, these costs can go up dramatically past some point. The significance is that water quality standards likely imposing smaller costs on agricultural production could perhaps be adapted with a lower burden of proof, whereas tighter water quality standards imposing larger costs would need to be more strongly justified.

- An overriding concern is whether or not agriculture is sustainable in terms of maintaining reasonable levels of profitability absent external drainage facilities. Economic results to date suggest that agricultural production is sustainable at least in the intermediate term even in closed basins provided growers are allowed to operate evaporation ponds with reasonable costs and environmental regulations. Agricultural production could also be long-term sustainable if a mechanism for salt removal from the ponds can be achieved.

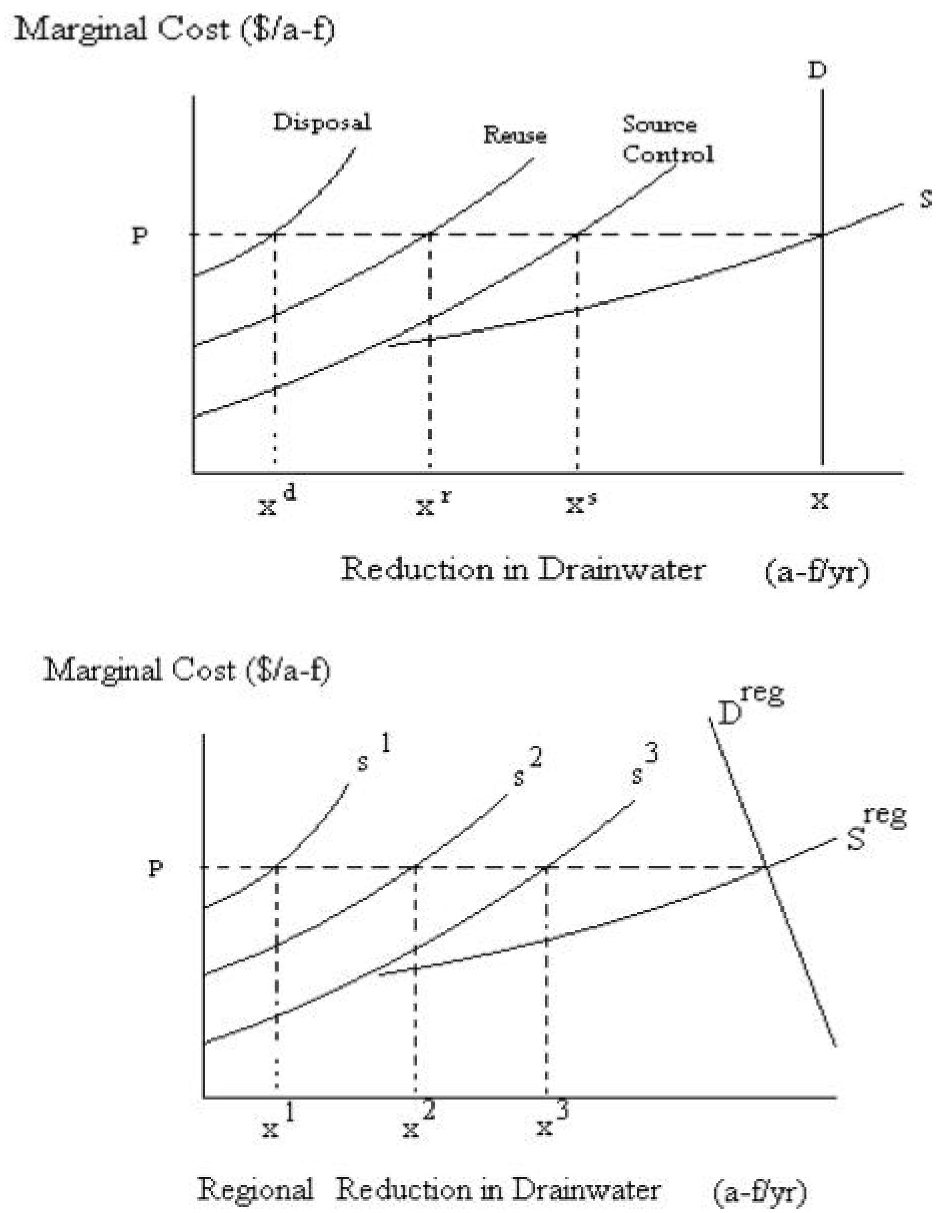


Figure 5- a) Marginal costs of drainage management options for one farm (top) and, b) the aggregate marginal costs and benefits for three farms in a region (bottom).

5. Significant Changes in Drainage Management Options Since the 1990 Management Plan

General:

The specific acreage goals for each drainage management option by Subarea, as presented in the 1990 Plan, are now recognized at best as general guidelines only. Strict adherence to those acreage recommendations is now seen as a hindrance to the development of combination of new drainage management options and the implementation of the most technologically and economically efficient drainage management measures. The AHCC recognized that no acreage recommendations would be a part of the Committees recommendations.

Specific:

Drainage Reuse

Although progress in development of sequential reuse systems has been made, it has not been implemented as predicted by the 1990 Plan. Blended reuse systems are now being tested and implemented. More emphasis is now being placed on developing forage and halophytic crops with reused drainage water, as opposed to tree crops that have not generally proven to be effective. Drainage reuse has also been extended to include aquaculture in evaporation ponds and water supply for compensation wildlife habitat.

Drainage Treatment

Treatment systems were not sufficiently advanced or economical to allow for recommendation at the time of the 1990 Plan. Now reverse osmosis filtration systems for the removal of both salt and selenium are ready for demonstration and implementation. Several pilot or fully operating RO systems are being constructed or proposed for construction in all three Subareas. However, the brine disposal from a large RO system still remains untested. Solar distillation systems are also being tested for as a means of separating salts from drainage water. Research and development of biological treatment systems, especially wetlands treatment systems not envisioned in the 1990 Plan, is ongoing and showing promise. Water from filtration or distillation treatment systems may be reused directly on-farm. Biologic treatment systems may be integrated with other drainage management systems, such as evaporation ponds and river discharge, in order to improve wildlife safety.

Land Retirement

Although land retirement programs are under development, the year 2000 goals of the 1990 Plan will not be fully achieved. In the 1990 Plan, land retirement was seen as a last resort measure to manage agricultural lands with high concentrations of selenium in the soil and groundwater. Ironically, just as treatment systems are now being developed that could eliminate the need for land retirement as originally intended, the purpose of land retirement in three active programs has now grown to include wildlife habitat restoration for endangered species (USBR, EA and FONSI, 1999) and water transfers (Westlands and Widren Water Districts). Possible environmental degradation of retired lands as a result of salinization and selenification that may require modified land management was not recognized in the 1990 Plan.

Evaporation Ponds

The efficacy of structural and operational modifications to traditional evaporation ponds in reducing wildlife use was not foreseen by the 1990 Plan neither was the high bird productivity of compensatory mitigation wetlands. The 1990 Plan recommended evaporation pond: mitigation habitat ratio of 1:1 (for one acre of pond with selenium more than 2 ppb one acre of mitigation habitat was recommended). Based on the recent findings from studies at mitigation habitats, the Waste Discharge Requirements issued by CVRWQCB for evaporation ponds have required fewer habitats to mitigate the unavoidable impacts than recommended by the 1990 Plan. Traditional evaporation ponds can now be managed to reduce wildlife impacts and meet regulatory requirements, although at a high economic cost. Non-standard evaporation ponds proposed in the 1990 Plan have not yet been developed for use in the San Joaquin Valley, although solar ponds are still being recommended for development. Solar evaporators, not proposed in the 1990 Plan, have proven efficacious in evaporating high salt and selenium drainage water, while minimizing the hazard to wildlife, as the final component of sequential reuse systems.

Source Reduction

Improved methods of distribution uniformity and water use efficiency allow source reduction to nearly meet or exceed the projections of the 1990 Plan. Although measures have been widely implemented and considerable reduction achieved, further reductions can be made in some areas. In particular, techniques for increased direct use of shallow groundwater by deeper rooted and salt tolerant crops may be refined and more widely implemented.

Groundwater Management

Unlike all the other recommendations of the 1990 Plan, no effort has been made to implement groundwater management as a drainage management measure due to its perceived infeasibility. However, lowering of the shallow groundwater table has been an indirect effect of ongoing groundwater pumping, particularly during drought years, and the Technical Committee concluded that coordinated, monitored, and managed groundwater extraction could still be an effective means to manage drainage through lowering the regional shallow groundwater table. The Committee further outlined the technical and regulatory process that would allow for implementation. However, an exception to the regulatory prohibition of degradation of a water supply would have to be made in order for groundwater management to be implementable.

River Discharge

The future focus of management of drainage discharge to the San Joaquin River is on meeting appropriate load limits, which may incorporate more emphasis on water year types real-time information for management. A change in selenium criteria may be developed which would be founded on new data that could be utilized to determine the site-specific impacts of selenium in the environment. Neither of these approaches were a part of the 1990 Plan recommendations. The 1990 Plan recommendation to extend the San Luis Drain (a part of which now functions as the Grassland Bypass Channel) to the San Joaquin River below the Merced River confluence is now viewed as requiring additional analysis to determine its need. The 1990 Plan projected increased discharge of drainage water to the SJR subject to water quality objectives. The CVRWQCB Basin Plan amendment, presently underway, and establishment of more restrictive salinity objectives may further limit the discharge of drainage water to the River. Compliance with such more restricted water quality objectives would require implementation of measures to reduce salt discharge to the River. Treatment, reuse coupled with solar evaporators and evaporation ponds or disposal facilities may present opportunity to meet the new requirements.

Salt and Selenium Utilization

A major aspect of the 1990 Plan was the postponement of addressing the issue of finding an appropriate end-point for salt. The 1990 Plan left the salt to gradually build-up in the Valley soils, stored it in the semi-confined aquifer by groundwater management, discharged it to evaporation ponds with a relatively small amount being discharged to the San Joaquin River. The AHCC report recognizes the separation of salt from Valley soils and groundwater and disposal or utilization of that salt to be the fundamental issue of drainage management and agricultural and environmental sustainability. Commercial utilization of salts separated from agricultural drainage water was not a component of the 1990 Plan. Opportunities for the commercial marketing and utilization of some salt products may exist if economical separation, purification to commercial standards, and marketing of agricultural salts can be developed. The same is true for selenium, with the addition of the now recognized important health and nutritional benefits of selenium in the diets of both humans and animals.

6. Implementation Status Since Publication of the 1990 Plan.

The 1990 Plan objectives were to sustain agricultural productivity, protect water quality, fish and wildlife and public health. Below the status of achieving these objectives is discussed.

Agricultural Sustainability

To sustain productive irrigated agriculture, shallow groundwater in the crop root zone must be controlled and low root zone concentrations of salt and boron must be maintained. Accordingly, the status of shallow groundwater in the Valley is an important indicator of the efficacy of management efforts to maintain productive agriculture.

SJVDP estimated that 870,000 acres would have shallow groundwater by 2000, with about 410,000 acres projected to have groundwater salinity and boron concentrations sufficiently high to limit agriculture. The low-quality, shallow groundwater areas in 2040 were projected to be approximately 910,000 acres.

Groundwater monitoring from 1991 to 1994 indicates (Figure 3) that only about 54 percent of the total acreage of shallow groundwater in the 0-5 foot depth range predicted for 2000 had occurred (470,000 out of 869,000 acres predicted). However, the 1997 total acreage with groundwater within 10 feet of the surface is more than 1,200,000. This area is greater than 910,000 acres predicted 5-foot-deep shallow groundwater area in 2040. Between 1995-1997, the areas with a shallow water table within 5 feet have significantly increased compared to 1991-1994 period. This is also exhibited in areas with a water table within 10 feet. Even though the present observed area with groundwater within 5 feet of the surface is less than projected, the area with groundwater within 10 feet of the surface is increasing rapidly. The 1990 Plan projected that the area of shallow groundwater within 5 feet would increase between 2000 and 2040, despite 1990 Plan implementation, from 870,000 to 1,000,000 acres.

Except for limited discharge to the River, evaporation pond is the 1990 Plan only recommended management measure that addresses removal of salts from soils in the westside of the Valley. Accumulation of salts in soils and in shallow groundwater in the Valley is continuing.

Fish and Wildlife Protection

The Central Valley Project Improvement Act provision of water supply for fish and wildlife resulted in a significant re-allocation of water for wildlife habitat in Grasslands and other areas. The Grasslands Bypass Channel implemented in 1997 eliminated conveying of subsurface drainage water in Salt Slough, part of Mud Slough, and Grasslands channels. Conveying higher quality water in water supply channels is a significant benefit for Grasslands' wetland habitats.

Evaporation pond modification, management, and creation of mitigation, and compensation habitats have significantly reduced adverse impacts on aquatic birds using evaporation ponds.

Water Quality

Implementing 1990 Plan recommendations, primarily source control and on-farm or district-level reuse, contributed to reduction in salt, selenium, and boron loads in drainage water discharged from the Grasslands subarea to the San Joaquin River. Selenium load limits established by the CVRWQCB for the use of the Grasslands Bypass Channel have been met in water year 1999. This is primarily due to the implementation of drainage management measures in the Grasslands Drainage Area. Still, water quality objectives periodically are not met under present conditions. Further measures will need to be implemented to meet CVRWQCB's water quality objectives. It is uncertain what measures and costs will ultimately be necessary to attain acceptable water quality. The CVRWQCB is in the process of amending its Basin Plan, which is expected to develop salinity objectives for SJR upstream of Vernalis. Such new objectives will further limit discharge of drainage water containing salts to the San Joaquin River. It is possible that future salinity objectives would create more stringent limits for drainage discharge to the River, thus necessitating implementation of projects that would further reduce drainage discharge. But to sustain agricultural productivity it is necessary to remove salts from drainage water, projects such as on-farm drainage reuse on salt tolerant crops and trees coupled with evaporation ponds or solar evaporators and drainage treatment will need to be part of the long-term plan.

Public Health

Selenium intake through drinking water was not a serious concern because concentration of selenium in potable water supplies in the Valley has been less than 2 ppb. (EPA standard is 50 ppb). SJVDP's primary public health concern relating to drainage water was human intake of selenium from consuming fish and wildlife impacted by selenium. This remains a concern. Human health warnings issued by Department of Health services for fish and waterfowl in the Grasslands area and waterfowl in the Bay-Delta Estuary remain in effect.

Implementation of 1990 Plan

The 1990 Plan contained specific recommendations with acreages for each action. The Plan also identified a number of actions and recognized that those actions have to be implemented as soon as final planning is completed. Progress made in implementation of these actions are presented in Table 3. Table 3 also identifies a few recommended actions that have not been accomplished so far.

Table 3- Status of the 1990 Plan Conclusions and Recommendations

1990 Plan Recommendation	Status
Implementation Recommendation 1 – Implementation Of Recommended Plan; Priority Activities	
Local, State, and Federal water organizations and authorities should consider the recommended plan and explicitly adopt those parts appropriate for their long-term strategy of contributing to the management or solution of the drainage problems of the west side San Joaquin Valley.	
The following Plan components should be implemented as soon as final planning is complete, funding and applicable clearances can be obtained, and agreement can be reached. An asterisk (*) following a plan component indicates there is a related current local initiative that should become part of the plan component.	
Northern Subarea	
• *Investigate, in detail, measures that may be needed if stricter salt standards are established for the San Joaquin River/Delta*	• CVRWQCB Basin Plan has initiated to establish stricter salinity standards upstream of Vernallis. No detailed investigation for development of measures has been initiated.
Grasslands Subarea	
• *Use the Grassland Task Force water districts as the nucleus of a regional drainage entity to coordinate and jointly manage subarea-wide drainage problems.**	• Grasslands area farmers have created an entity to coordinate and manage drainage problems in Zone A of Grasslands subareas. A joint powers authority has been formed which includes Grasslands, Westlands, and part of Tulare subareas.
• *Provide the facilities required to intercept contaminated subsurface drainage water now being discharged into open channels within the grasslands wildlife habitat, and convey these to the San Luis Drain.**	• The Grasslands Bypass Channel currently in operation, bypasses drainage water around wetlands for discharge to Mud Slough.

.

Table 3- Status of the 1990 Plan Conclusions and Recommendations

1990 Plan Recommendation	Status
• *Renovate and extend the San Luis Drain, bypassing 20,000 acre-feet of contaminated drainage water around wetlands (similar to the Zahm-Sansoni-Nelson Plan).**	• A segment of the San Luis Drain is used under an agreement between USBR and SLDMWA to intercept drainage water and convey it to Mud Slough and the SJR.
• *Improve on-farm water conservation and source control on all irrigated lands and reduce deep percolation on lands having drainage problems by 0.35 acre-feet per acre per year (on the average) as soon as possible.**	• Significant improvement in on-farm water conservation and drainage reuse as well as district-wide reuse has been accomplished. The target of 0.35 af/a has been met in dry years. District policies limit pre-irrigation to 8" which reduces drainage.
• *Intensify and complete local demonstration projects on sources control and treatment of drainage water. (Work already under way in Broadview, Panoche, and Pacheco water districts.)**	• Source control measures are in place in Zone A of the subareas. Demonstration projects on drainage water treatment are continuing. Prospects for removal of selenium from drainage water have improved.
• *The U.S. Bureau of Reclamation should actively seek authority to reallocate 74,000 acre-feet of water annually from the Central Valley Project to replace drainage water used on wetlands before 1985.*	• USBR Action Plan and the facilities are due for completion in 2002. Level II supplies have been delivered since 1992 and level IV supplies are purchased for delivery in 10% increment to get full allocation in 2002.
• *Restore drainage-contaminated wetlands*	• No specific project has been aimed at restoring wetlands except CVPIA's requirement of acquiring water for wetland enhancements.
• *Provide 20,000 acre-feet of water to the Merced River each October to attract migrating fish from drainage water discharging to the San Joaquin River.*	• Has been accomplished by Merced Irrigation District fish flow releases.
Westlands Subarea	
• *Improve on-farm water conservation and source control on all irrigated lands and reduce deep percolation on lands having drainage problems by 0.35 af/a/y (on the average) as soon as possible.**	• WWD water management program has provided for source control measures. Drainage reduction goals of 0.35 af/a has been met in extremely dry years.

Table 3- Status of the 1990 Plan Conclusions and Recommendations

1990 Plan Recommendation	Status
• *Accelerate the pace and increase the number of field demonstrations of source control measures and drainage water treatment and reuse on trees and removal of selenium from drainage water.**	• WWD has participated in drainage treatment research in the past. Loans have been used to purchase new irrigation systems. Treatment projects have been terminated. WWD has participated in a drainage reuse demonstration project.
• *Develop guidelines for retirement of irrigated lands that have high selenium concentrations in shallow ground water and that are difficult to drain.**	• USBR has developed preliminary guidelines and plans to acquire up to 15,000 acres as a demonstration project to finalize its guidelines for land retirement. CVPIA authorizes USBR, USFWS, USBLM to retire more acres in CVP service area.
• *Design and develop a 5,000-acre demonstration unit of closely spaced, low-volume wells in the semiconfined aquifer for planned drawdown of the high water table.*	• This activity has not been pursued due to perceive infeasibility of ground water management to drawdown the water table.
Tulare Subarea	
• *Develop a formal association of water districts (built around the existing Tulare Lake Drainage District) for coordinated and joint management of sub-area-wide drainage problems.**	• An association of pond operators in the Tulare Lake Basin has been formed. (Central Valley Agricultural Evaporation Pond Operators, CVAPO). However, their function doesn't include joint management of sub-area-wide problems.
• *Improve on-farm water conservation and source control on all irrigated lands and reduce deep percolation on lands having drainage problems by 0.2 acre-feet per acre per year (on the average) as soon as possible.**	• Some degree of farm source control has been accomplished. Regional irrigation efficiency is reportedly high, but the goal of 0.2 af/a reduction has only been met in extremely dry years.
• *Accelerate the pace and increase the number of field demonstrations of source control measures and evaporation pond experiments, including especially the reuse of water on trees and modification of pond systems and their management to make ponds bird-free or bird-safe.**	• Demonstration projects on drainage reuse and reuses of water on trees have been conducted with limited success. Significant improvements in configuration of ponds and pond management have been accomplished. Effective hazing and creation of compensation habitat have been implemented.

Table 3- Status of the 1990 Plan Conclusions and Recommendations

1990 Plan Recommendation	Status
• *Demonstrate in the field the use of alternative safe-water habitat near an existing evaporation pond containing elevated levels of selenium.*	• Alternative safe-water habitat has been established in Westlake farms. Seasonal flooding in TLB and pre-irrigation provide alternative feeding area for birds.
• *Design and develop a 5,000-acre demonstration unit of closely-spaced, low-volume wells in the semi-confined aquifer for planned drawdown of the high water table in the area of good quality ground water in the Kings River Delta (Tulare Subarea water quality Zone E).*	• This activity has not been accomplished due to perceived infeasibility of groundwater management to drawdown water table.
Kern Subarea • *Kern County Water Agency and local water districts should form a drainage management entity responsible for coordination and joint management of subarea-wide drainage problems.*	• Not accomplished.
• *Improve on-farm water conservation and source control on all irrigated lands and reduce deep percolation on lands having drainage problems by 0.35 acre-feet per acre per year (on the average) as soon as possible.**	• Some degree of source control has been accomplished due to water supply shortages.
• *Initiate intensive studies of the ground-water resources of the old Buena Vista and Kern lakebeds.*	• Not accomplished.
Recommendation 2 - Source Control *The agencies with major responsibility for delivery of water to the study area (U.S. Bureau of Reclamation and California Department of Water Resources) should increase their work with the university extension systems and water districts to demonstrate ways to improve the efficiency of irrigation water application and thereby reduce potential drainage-water volumes.*	• The opportunity for cooperative work exists. Some demonstration projects have been implemented. More cooperative demonstration projects should be planned.

Table 3- Status of the 1990 Plan Conclusions and Recommendations

1990 Plan Recommendation	Status
Each water district should, by 1992, set objectives in their operation plans that would reduce deep percolation by the amounts stated in Recommendation 1 (preceding). State and Federal agencies should help local water districts accomplish their water conservation improvement plans.	• Improvements in irrigation systems have resulted in drainage reduction. State/Federal loans and grants have been provided. However, the drainage reduction goals have not been adopted by districts as targets in their operation plans.
Recommendation 3 - Financing Source Control Measures *Both the Federal and State governments should explore ways of providing a portion of the financing needed to implement irrigator source-control actions and to invigorate existing programs. The U.S. Soil Conservation Service, (NRCS), and U.S. Bureau of Reclamation both have programs that could aid in financing irrigator actions. The State of California, through the Department of Water Resources, the Department of Food and Agriculture, and the State Water Resources Control Board, could provide loans and grants for source-control actions, if funds were made available.*	• SWRCB is the only agency that has loans for source control action. Considerable amount of loans have been provided for irrigation system improvements. USBR and DWR have provided funding for source control demonstration projects. USDA, NRCS has also contributed resources to irrigation improvement and drainage reuse projects. Proposition 204 provided funding to DFA for drainage reuse which is being implemented in cooperation with SWRCB and DWR.
Recommendation 4 - Joint Technical Assistance *The U.S. Department of the Interior and the State of California should jointly develop a technical assistance program to ameliorate the drainage problem, by providing water districts with geohydrologic and economic information and analytical techniques useful in investigating local areas for possible conjunctive surface- and ground-water use, land retirement, on-farm drainage, source control, and reuse. Technical assistance is also needed in environmental impact assessment, toxicity assessment, and habitat restoration.*	• The DOI and State agencies have various programs to provide technical assistance to districts. More coordination and cooperation among agencies is needed to accomplish this goal. Also needed is more coordination in funding as well as new funding.

Table 3- Status of the 1990 Plan Conclusions and Recommendations

1990 Plan Recommendation	Status
Recommendation 5 - State of California Lead in Water Conservation *The State of California should expand and intensify its program of on-farm water conservation to focus especially on demonstrating alternative source control measures on drainage-problem lands.*	• DWR has an on-farm water conservation and drainage reduction program. Limited funding has curtailed projects. CalFed water use efficiency program can provide the means for accomplishing this goal. Implementation of EWMPs is intended to help improve on-farm irrigation efficiency.
Recommendation 6 - Federal and State Programs' Adjustment *The State of California and the U.S. Department of the Interior should jointly consider the findings, forecasts, and plans of the Drainage Program with respect to drainage problems, and should look for opportunities to encourage amelioration and resolution of these problems. This should be achieved through ongoing operations, planning, construction, and - if considered necessary - new legislation, promulgation of rules and regulations, and appropriate language in contracts and administrative reviews.*	• State/Federal agencies have participated in activities including Grasslands Bypass project agreement, Waste Discharge Requirements for SJ River and evaporation ponds, planning for land retirement, monitoring, demonstration projects, research. Now legislation in the areas of regulating solar evaporation and legislation for funding may be needed. The AHCC report and the technical and subarea reports present further opportunities to ameliorate drainage problems.
Recommendation 7 - Western U.S. Applications *The U.S. Department of Interior should consider the information, techniques, and experience accumulated in the Drainage Program and extend appropriate aspects of the knowledge base to other land areas in the western United States that are experiencing similar agricultural drainage and drainage-related problems.*	• Information collected has been published and made available to agencies.

Table 3- Status of the 1990 Plan Conclusions and Recommendations

1990 Plan Recommendation	Status
Planning *The general plan for reducing or solving drainage and drainage-related problems outlined in this report provides a framework into which many actions can be fitted. However, before many of the actions can move forward, additional work is needed to refine estimates of their scope and effects. Generally, this additional planning will occur at local, State, and Federal levels, and at combinations of each.*	• Local planning, demonstration projects, research, and monitoring have been conducted by farmers, districts, pond operators, government agencies to implement practices to manage drainage problems. Pond compensation habitat needs have been refined. Land retirement guidelines are being prepared by conducting a 15,000-acre demonstration project. Specific load limits have been issued for River discharge.
Recommendation 1 - Water District Plans *With financial and technical assistance from State and Federal agencies, water districts should lead in developing plans to:*	
• *Identify lands in drainage problem areas in which the combined characteristics of high concentrations of selenium and difficult-to-drain soils would make these lands candidates for retirement from irrigation.*	• WWD has worked with USBR in the CVPIA authorized land retirement program to identify candidate lands for retirement.
• *Identify locations in drainage problem areas where there may be an opportunity to lower the high water table by pumping from deep in the semiconfined aquifer (above the Corcoran Clay), and design the facilities, reach agreements, and obtain policy approvals required to carry out pumping.*	• This work has not been pursued due to perceived infeasibility. However, WWD conducted a demonstration project to pump shallow ground water to lower water table. The project was discontinued due to unacceptable performance and poor water quality.
Recommendation 2 - State Water Project Area *Within the State Water Project service area, the State of California should lead in planning for the regional drainage-water treatment and disposal needs that will arise from management and reuse of drainage water within local water districts.*	• No planning work has been initiated by the State for regional treatment and disposal needs of SWP area. However, a demonstration project for reuse of drainage water has been funded by USBR and DWR. A drainage treatment research project was conducted for several years by DWR, USBR, and WWD. DWR has a drainage treatment program with limited funding and continues to explore treatment options.

Table 3- Status of the 1990 Plan Conclusions and Recommendations

1990 Plan Recommendation	Status
Recommendation 3 - Federal Water Service Area *Within the Federal water service area, the Department of the Interior should lead in planning for the regional drainage-water treatment and disposal needs that will arise from management and reuse of drainage water within local water districts.*	• SWRCB and WWD (USBR may join) have signed a MOU to begin planning for resolution of regional drainage water management including disposal options. Formation of a joint powers authority may expand the scope of MOU to areas beyond WWD area.
Recommendation 4 - Joint Planning for Ground-Water Management *Plans for installation and operation of well fields designed to pump from the semi-confined aquifer to lower the high water table should be completed cooperatively by Federal and State agencies and water districts. In the Federal service area, the Bureau of Reclamation should work with Westlands, Broadview, Panoche, San Luis, and Firebaugh Canal water districts to design well fields for areas identified in this report. In the State service area, the Department of Water Resources should work with Kern County Water Agency and Empire Westside, Riverside, Stratford, and Laguna irrigation districts, Lakeside Irrigation Water District, Kings County Water District, and Kings River Conservation District for the same purpose. Services of the U.S. Geological Survey should be used in locating favorable areas and in developing plans.*	• This recommendation has not been pursued.
Recommendation 5 - Joint Planning for Water Delivery *Federal and State fish and wildlife agencies, in cooperation with private wetland owners, and Federal and State water development agencies should jointly plan the facilities required for delivery of water to wildlife areas affected by subsurface drainage water.*	• USBR San Joaquin Basin Action Plan due for complete implementation in 2002 has developed plans for facilities required for water delivery to wildlife areas. Some facilities have been completed.

Table 3- Status of the 1990 Plan Conclusions and Recommendations

1990 Plan Recommendation	Status
Monitoring *To properly implement management of drainage and drainage-related problems, both the problems and the progress in solving them must be monitored. This is especially important because of the changing nature of the drainage problem and the flexible array of measures required for management. Monitoring all aspects of the problem and the effects of management will be critical to using the plan as a flexible guide to remedial actions*	• A regional drainage-monitoring plan was prepared in 1994 by SJVDIP to monitor soil, groundwater, surface water, and biota in the Valley. The plan has not been implemented due to lack of funding. Monitoring is in place for SJ River, Grasslands Bypass Channel, and evaporation ponds as required by CVRWQCB. Groundwater elevation is monitored by DWR, USBR, and districts. DWR conducts drainage water quality monitoring in the Valley. The 1994 monitoring plan should be updated and a comprehensive plan developed to assess the condition and effectiveness of implementation actions.
Recommendation 1- Local Water Agencies *All local water supply and drainage agencies should participate in joint coordinated programs to monitor the quality and volume of drainage in the collection, treatment, and or disposal systems.*	• Local agencies that discharge drainage water to ponds or the River are under waste discharge requirements and monitor the quality and volume of drainage water. No coordinated regional monitoring has been established.
Recommendation 2 - Joint State/Federal *The U.S. Department of the Interior and the State of California should jointly design a scientifically reliable and cost-effective network of physical and biological monitoring stations that will detect change in the environment caused by subsurface agricultural drainage problems and attempts to solve these problems. Areas expected to experience expansion of high water tables should be included.*	• Even though biological monitoring is being conducted by agencies or districts, no monitoring is conducted to detect change in the environment caused by potential expansion of high water table areas or accumulation of salts in soils. The 1994 monitoring plan needs to be updated and implemented to achieve this goal.
Additional Study *During the six-year life of the Drainage Program, the absence of reliable information made it necessary for the Program to fund basic research, as well as to fund investigations directly relevant to solving drainage problems. Some additional study is needed to provide detailed information for feasibility determinations.*	

Table 3- Status of the 1990 Plan Conclusions and Recommendations

1990 Plan Recommendation	Status
Recommendation 1 - Study Needs	
Water and land managers, universities, agencies, and individuals should emphasize the following study categories and subjects, and support the development of information transfer programs to extend study results to appropriate user groups.	
Drainage Management	
• *Develop measures to renovate or close aged or toxic evaporation ponds.*	• Criteria for pond closure has been developed.
• *Develop a cost-effective treatment to remove selenium from drainage water.*	• Selenium removal is still not cost effective. Selenium has been harvested along with salts from drainage water by crystallization in solar evaporators.
• *Perform field tests of tolerance of agricultural crops, halophytes, and salt-tolerant trees to constituents in drainage water.*	• Considerable research and testing has been made in this area. Salt tolerant crops and plants are identified.
• *Develop effective training programs for personnel involved in drainage management.*	• DWR sponsors drainage workshops and has a water conservation-training program in cooperation with Cal Poly.
• *Investigate the propagation and marketing of salt-tolerant crops that use saline drainage water as an irrigation supply.*	• More work needs to be done in selection and propagation of such crops.
• *Demonstrate the use of an accelerated evaporation system, using a sprinkler system similar to the University of Texas at El Paso's experimental system and the use of a temperature-gradient solar pond system for salt disposal and generation of electricity.*	• A solar evaporator that is similar to the 1990 Plan accelerated rate evaporation pond has been tested. The evaporator shows promise. The objective is to separate salts and find a use for it. Present regulations may limit the extent of operation of solar evaporators. Opportunities for salt utilization and salt marketing is being explored utilizing Proposition 204 funds at DWR. Temperature-gradient solar ponds for salt disposal need further work.

7. Coordinated Drainage Management Recommendations by Subarea

The result of Phase I of the SJVDIP Activity Plan was eight Technical Committee (TC) reports (SJVDIP 1999a-1999h) and three Subarea reports (SJVDIP 1999i-1999k), reproduced and distributed as individual documents from February to April 1999. The TC reports contain numerous suggestions and recommendations for future actions and directions that would advance the development and implementation of each of the in-valley drainage management options. The Subarea reports contain the existing programs and future directions that each Subarea intends to pursue to advance drainage management in their respective region. One of the objectives of the Activity Plan was to create a synthesis of the approaches and recommendations of the TC and Subarea reports. This objective is now realized through the coordination of recommended actions that follows.

Procedure

The first step in preparing the sets of coordinated recommended actions was the extraction of recommended actions from the TC reports and the grouping of related actions. Actions include recommendations for further study and research, development of new models and refinement of existing models, economic studies, pilot and demonstration projects, and full implementation of selected actions. Not all recommended actions in all reports carry the same significance. Some reports have concluding chapters detailing the specific actions analyzed by the TC and recommended for implementation. Other reports made general recommendations after analysis within the body of the report, suggested actions without analysis, and implied recommendations based on the results of studies completed by others. All of these suggestions and recommendations were extracted and included within the grouped lists of coordinated actions.

Each TC recommended action, as it appears below (indicated by a bullet) is followed by a number code. The single numeral code preceding the colon refers to the sequential number of the TC report in which the recommended action may be found. For example, 8: refers to the Salt utilization technical committee or task 8 report. (There were eight TC's: 1- Drainage Reuse, 2- Drainage Treatment, 3- Land Retirement, 4- Evaporation Pond, 5- Source Reduction, 6- Groundwater Management, 7- River Discharge, and 8- Salt Utilization.). The numbers after the colon are the page numbers within the specified report where the recommended or suggested action is described or mentioned. The TC recommended actions are grouped under Subarea program and planning objectives extracted from the Subarea reports. These objectives are grouped into larger categories that are indicated by the Roman numeral and letter codes that precede each Subarea objective. Following each Subarea objective is the page number in the Subarea report where it is discussed. The Subarea objectives and coordinated TC actions are separated into short-term and long-term groupings. No specific time frame is attached to these groupings. Short-term refers to actions that is currently being implemented or is ready for implementation, including preliminary steps of multi-phase long-term actions, and for which expected results should be directly realized. Long-term refers to actions that are not fully ready for implementation, or that will require further planning, or for which expected results are uncertain or will not be realized for an extended period of time.

The reason why the Subarea objective codes do not always follow in sequence is that not all Subarea objectives are included in this list. Only those objectives are included that have counterparts or related recommended actions in the TC reports. If the TC reports did not address or did not make any recommendations in support of a given Subarea objective, that objective was not included in this list. Likewise, not all TC recommendations can be coordinated with Subarea objectives. In some cases, possible actions recognized by the TC's have not been identified in the Subarea reports. These TC recommended actions are included at the end of each Subarea coordinated list as a set of TC actions potentially beneficial to the specified Subarea, if the actions were to be given further consideration for inclusion in each Subarea drainage management plan.

Purpose

A number of different approaches to the coordination of TC and Subarea recommended actions and objectives could have been taken. For example, actions could have been grouped by TC rather than Subarea, thereby giving primacy to specific drainage management options to which the Subarea objectives would then be linked. This approach would have the benefit of coordination for each management option, but would have the detriment of an imposition of management directions onto the Subareas without recognition of the substantial Subarea accomplishments. Another approach would have been grouping TC recommendations and Subarea objectives by drainage problem, such as shallow groundwater reduction, drainage management and disposal, salinity reduction and salt balance, trace element management, and environmental safety. While this approach would have the benefit of overall ecosystem management, the important Subarea variations in the physical environment, agricultural practices, and socioeconomic resources would have been obscured.

The selected approach for coordinated actions gives primacy to the regional plans and objectives of each Subarea. The benefit of this approach is to give primacy to the proactive advances made by each Subarea, and to recognize the significant differences in Subareas that require a region-specific approach. In this approach, government agencies and the University of California play a subordinate role in support of and as advisors to the Subareas in the development of drainage management plans, if such plans are developed.

Results

The result of this exercise in developing coordinated lists of drainage management actions is the identification of directions that hold the most promise for future advancement. In a number of areas, substantial progress has already been made, or the means for progress already substantially exists with the promoting or implementing district or agency. The currently most important areas for emphasis for each Subarea (as identified in the next sentence) are those in which the most progress needs to be made, and the areas in which assistance of government agencies and the University of California could be of the most benefit at the present time. The areas of primary emphasis are as follows: for the Grasslands subarea, River discharge and drainage treatment; for the Westlands subarea, drainage reuse, drainage treatment, and land retirement; for the Tulare/Kern subarea, evaporation ponds and drainage treatment. More specific areas of emphasis are identified within each of these general areas in the coordinated listings below.

Usage

The following listing and organization of recommended drainage management actions have several potential uses.

(1) The coordinated actions list organized by Subarea provides a basis for continued cooperation and expanded joint drainage management programs between the Subareas and government resource and regulatory agencies, and the University of California.

(2) The list provides the SJVDIP Management Group with a detailed summary of the results of the first two phases of the Activity Plan, and provides a basis for making decisions about the future direction of the SJVDIP.

(3) The list provides Subareas with specific areas and items in which further advances may best help to promote regional drainage management programs.

(4) The list provides guidelines to government agencies that could aid in formulating the future direction of agency drainage management programs.

(5) The list provides funding agencies with specific tasks and subject areas that would be most efficacious in which to develop directed Request for Proposals and to grant funding.

(6) The action statements that follow are the result of a technical review of the current status of various drainage, salt, and trace element management measures. The action statements have not undergone a rigorous evaluation to determine site-specific suitability, nor economic efficiency and cost-effectiveness. No evaluation of potential environmental or other impacts has been made. The specific action statements and their correlation as appear below are suggestive only, and are only intended as framework for future development and possible implementation.

SJVDIP Coordinated Drainage Program for the Grasslands Subarea

Short-Term Program

II.A. Continue to upgrade real-time monitoring program and biota toxicity testing (6-7)

- Continue and expand support of essential water quality and flow-monitoring stations along San Joaquin River and tributaries (7:88, 90, 96)

- Continue efforts to gain support of the San Joaquin River Management Program-Water Quality Subcommittee (SJRMP-WQS) salinity water quality forecasting system by enhancing forecast accuracy and reliability and expanding information delivery systems (7:88, 90, 96)

- Develop funding strategies to make the monitoring system self-supporting (7:96)

- Continue collection of Grassland Bypass project biologic data (7:96)

- Support continued efforts of the SJRMP-WQS to improve cooperation and coordination of operations among diverters, dischargers, and other beneficial users of the SJR (7:88, 96)

- Continue efforts to gain support for a real-time management system for salt, boron, and molybdenum by tailoring the system design to the operational needs of users (7:87, 90, 96)

II.E. Develop and implement drainage treatment (9, lines 18-20)

- Determine primary purpose of treatment: (1) reduce toxic constituents below hazardous levels; (2) achieve standards for agricultural drainage reuse; (3) meet water quality objectives for surface water discharge; (4) reduce toxic constituents below wildlife risk level (2:1-2, 26)

- Perform economic assessment of membrane treatment implementation (2:8)

III.H. Evaluate feasibility of developing Integrated On-Farm Drainage Systems (IFDM systems) (L5)

- Develop customized and flexible regional and site-specific reuse system designs (1:)

- Determine optimal blending/cyclic reuse strategies (1:)

III.I Evaluate feasibility of land retirement under specified criteria (L5, 20-21) (see Westlands Subarea)

I.D. Continue irrigation and drainage workshops (5)

(Review Source Reduction Technical Committee actions for completeness)

Long-term Program

III. D. Develop site-specific selenium water quality objectives as alternative compliance requirements (2, L13-15)

- Develop a better understanding of sediment biogeochemistry, organoselenium pathways, and selenium assimilatory capacities (see detailed project list, 7:93-94)
- Support selenium and mass balance studies to measure sources and sinks in aquatic ecosystems (7:92)
- Conduct monitoring and research on the long-term effects to the SJR and Delta ecosystems of selenium from drainage (7:93)
- Conduct research to evaluate temporal and site-specific selenium criteria sensitive to spatial and temporal variations in toxicity (7:89-91, 94)
- Develop site-specific and seasonal chronic water quality criteria for selenium (7:89-91, 94-95)
- Develop information needed to show that real-time management is at least as protective of the environment as the current load-based regulatory process (7:96)
- Seek changes in the regulatory limits placed on selenium discharges (7:96)
- Re-evaluate selenium chronic water quality criteria (2:17) (see T.C.4, 7)
- Conduct research to establish site-specific water quality parameters/ regulatory criteria that accurately reflect the bio-accumulation and toxicity of selenium speciation in the food chain (4:24-25, 46, 71-72) (see River Discharge Technical Committee Report)

III.E. Develop a real-time drainage discharge operation (L5, 15-16)

- Develop continuous selenium and boron sensors for use in the SJR and tributaries (7:92)

- Continue developing drainage control and management strategies, including source control, drainage reuse, drainage treatment, etc., that will allow full participation in a continuous real-time management system (7:87-88, 91, 96)

- Support boron mass balance studies to measure sources and sinks in aquatic ecosystems (7:92)

- Conduct research on the sub-lethal and chronic impacts of boron and boron interactions on fish and other aquatic species (7:92)

- Conduct research on the effects of sulfate salinity on Chinook salmon smolts in the San Joaquin River (7:92)

III.F. Develop measures to decrease discharges of boron, molybdenum, and salt (1, 3-4)

- Develop continuous boron sensors for use in the SJR and tributaries (7:92)

- Encourage research and field documentation of boron effects and salinity/boron interactions on crop yields (7:92)

- Monitor forage irrigated with reused drainage for possible molybdenum impacts on young cows (7:92)

- Expand opportunities for salt separation and harvest (8:)

III.A. Develop surface pond drainage storage as an alternative to the lack of benefit from soil profile storage (8, L12)

- Design and construct wildlife-safe drainage holding ponds to facilitate real-time management (7:93)

- Develop solar pond technology operating guidelines, estimate potential energy production, and evaluate economic factors (2:10, 26)

- Investigate selenium exclusion from the solar pond food chain (2:10)

- Evaluate the technical and economic feasibility of salt utilization in solar ponds (8:34)

- Prepare an EIR and establish a pilot solar pond project (8:34)

- Develop brine shrimp aquaculture (4:65-66)

- Investigate selenium partitioning and isolation as a result of pond stratification (4:64-65)
- Advance research and development of algal bioremediation (4:41-45)

II.E. Develop and implement drainage treatment (9, L18-20)

- Continue research and development to improve membrane technology (2:8-9)
- Develop integrated biological, chemical, and physical treatment technology for cost-effectiveness and optimal objective accomplishment (2:27)

III.G. Evaluate feasibility of extension of the San Luis Drain downstream of the Merced River (L5)

- Evaluate the need and merit of extension of the SLD to the SJR in order to expand opportunities for real–time management, in comparison with other options (7:91-92, 96)

Recommendations of the SJVDIP Technical Committees Potentially Beneficial to the Grasslands

- Expand opportunities for salt and selenium separation and harvest (8:)
- Develop existing and new selenium products and markets (8:)
- Develop biological treatment methods (including selenium volatilization) (2:)
- Improve soil quality management (1:)
- Improve trace element management (1:)
- Implement crop use of shallow groundwater (5:)
- Consider establishing district-level groundwater data collection and evaluate management opportunities (6:)
- Consider for implementation the Groundwater Management TC recommendations for SJVDIP actions such as developing planning models, incentive and support programs, workshops, and JPA formation, where feasible to encourage groundwater management (6:)

SJVDIP Coordinated Drainage Program for the Westlands Subarea

Short-Term Program

I.B. Continue implementation of the water conservation program (33-35, 40)

[All Source Reduction Technical Committee actions not already implemented may be included]

- Develop pressure chamber methods or modified crop coefficients to facilitate implementation of shallow groundwater management in coordination with surface irrigation (5:22-23)
- Conduct field trials to evaluate optimal pre-irrigation drainage and salinity reduction methods (5:28)

I.C. Continue to encourage achievement of a five-percent leaching factor (24)

- Improve long-term salinity management through crop rotation, irrigation management, adequate leaching, and on-farm or district drainage (1:9-12)
- Improve sodium management through expanded use of gypsum combined with re-tillage (1:17-20)

II.A. Continue cooperation with the USBR Land Retirement Program (35,40)

[All Land Retirement T.C. Report recommended actions may be included]

II.B. Develop WWD land and water rights acquisition program (36)

- Collect detailed, site-specific, and current soil and groundwater data from retired land sites (3:88)
- Analyze impacts of the transfer or reallocation of retired land water rights (3:84, 86)
- Develop and perform an economic evaluation and land selection method as described (3:88-90)
- Identify regional objectives, formulate land retirement scenarios, and evaluate short- and long-term consequences (3:90)
- Select alternative management strategies as necessary to avoid degradation of natural resources (3:87-88)

II.C. Continue support of sequential drainage reuse projects (35)

- Increase education and training in drainage reuse (1:)
- Establish drainage reuse working group (1:)
- Improve halophytic crop selection (1:)
- Develop customized and flexible regional and site-specific system designs (1:)

II.E. Continue both shallow and deep groundwater monitoring and distribution of data to growers for improved groundwater management (34,40)

- Implement crop use of shallow groundwater (5:)
- Continue district-level data collection and create groundwater evaluation actions (6:)
- Consider for implementation the Groundwater Management T. C. recommendations for SJVDIP actions such as developing planning models, incentive and support programs, workshops, and JPA formation, where feasible to encourage groundwater management (6:)

Long-term Program

III.A. Investigate the feasibility of evaporation ponds as technology and experience is improved (35)

[Potentially all Evaporation Pond T.C. report actions could be applicable if ponds are implemented]

III.D. Possibly intensify shallow groundwater management and use by crops (18)

- Implement crop use of shallow groundwater (5:)
- Consider establishing management agency, develop groundwater management plan, and gain plan approval (6:)
- Implement groundwater management plan (6:)

Recommendations of the SJVDIP Technical Committees Potentially Beneficial to the Westlands

- Improve drainage reuse economics and product marketing (1:)
- Establish goal of drainage treatment to facilitate optimal application (2:)
- Implement membrane technology (2:)

[Potentially all Salt Utilization TC actions may be included if Evaporation Pond TC or other means of salt separation are implemented]

SJVDIP Coordinated Drainage Program for the Tulare/Kern Subarea

Short-term Program

I.A. Develop updated water management plans (14-15)

- Develop and demonstrate economic incentives through combined technical, environmental, and economic systems approach where economic benefits exceeds costs (5:29)
- Improve irrigation scheduling and management, where applicable (5:)

I.B. Continue existing water transfers program for improved management of water supplies (8, 47)

I.C. Maintain drainage disposal fees to encourage drainage reduction and drainage management (15)

- Establish moderate fees for drainage discharge not to exceed the threshold for economic farming viability (5:26-29)

I.D. Continue improvements in irrigation scheduling (15)

- Develop pressure chamber methods or modified crop coefficients (5:22-23)

II.A. Continue use of crop-rotation cycle to optimize crop use of shallow groundwater (11)

- Implement crop use of shallow groundwater (5:) (3 actions)

II.B. Expand conversion of furrow irrigation to hand-move sprinklers, where applicable (14)

- Promote reduction in pre- and early crop irrigation depth of application through use of sprinklers and other methods, where applicable to soil types (5:19, 27)

II.C. Implement improved furrow irrigation techniques including skip-rows and shorter rows for appropriate soil conditions (14-15)

- Promote reduction of furrow lengths to one-quarter mile or less (5:10, 19, 27)

- Promote use of gated pipe and surge valves where appropriate (5:11, 19, 27)

II.D. Continue to develop alternative methods for irrigation (15)

- Promote conversion to drip and linear-move sprinkler systems where economically feasible (5:19, 25, 29)

- Promote conversion to higher value crops to make improved irrigation systems more cost-effective, if possible (5:24)

- Provide continuously available irrigation water supply to enable conversion to micro-irrigation systems (5:24)

III.A Continue development of drainage reuse for production of forage, pistachios, and other salt-tolerant crops (16-18)

[All Drainage Reuse TC recommended actions may be included]

III.B. Continue operation of evaporation ponds in compliance with WDR's, including monitoring and compensation habitat, where applicable (30, 31,46)
[All Evaporation Pond TC recommended actions may be included]

III.C. Continue development of aquaculture production in drainage water and commercial harvest of brine shrimp from evaporation ponds (19-20)

- Continue to develop and expand brine shrimp aquaculture (4:65-66)

III.D. Implement measures to further reduce drainage volume discharged to evaporation ponds in LHWD (38)

[See sections I, II, and III.A. above]

- Conduct field trials to evaluate optimal pre-irrigation drainage and salinity reduction methods (5:28)

III.E. Continue existing groundwater pumping contributing to lowering of shallow groundwater levels (7, 48-49)

- Continue agency data collection and establish district-level data collection and groundwater evaluation actions, where needed (6:42-43)

- Consider for implementation the Groundwater Management TC recommendations for SJVDIP actions such as developing planning models, incentive and support programs, workshops, and JPA formation, where feasible to encourage groundwater management (6:)

Long-term Program

IV.A. Continue to develop flow-through wetlands as treatment to reduce selenium from drainage to compliance levels without increasing the net biological risk (54-58)

- Determine primary purpose of treatment: (1) reduce toxic constituents below hazardous levels; (2) achieve standards for agricultural reuse; (3) meet water quality objectives for surface water discharge; (4) reduce toxic constituents below wildlife risk level (2:1-2, 26)

- Continue research in flow-through wetlands (2:17, 23-24)

- Continue to develop flow-through wetlands treatment system (4:33-34, 39-42)

IV.B. Design, construct, operate, and evaluate a mobile carbon aerogel capacitive deionization (CDI) desalinization process unit (59-60)

IV.C. Continue research in selenium volatilization from evaporation ponds through algal bioremediation with achievement of stated objectives (60-61)

- Continue research in algal bioremediation (2:15-16, 27)

- Advance research and development of algal bioremediation (4:41-45)

IV.D. Continue research in microbial bioremediation of selenium in evaporation ponds (62-63)

- Continue research and development of volatilization methods (2:18-20)

- Continue research and development of biological precipitation (2:20-22)

IV.E. Continue research and development of sulfur concrete made with evaporation pond salt (63-64)

IV.F. Continue operation of evaporation ponds

- Re-evaluate selenium chronic water quality criteria (2:17)

- Conduct research to establish site-specific water quality parameters/regulatory criteria (4:24-25, 46, 71-72)

- Monitor the effectiveness of pond closure measures on a long-term basis (4:36-39, 71)

- Develop and improve methods of salt separation and utilization, or disposal (4:10)

Recommendations of the SJVDIP Technical Committees Potentially Beneficial to the Tulare/Kern Subarea

- Continue research on membrane technology and implement where economically feasible (2:)

- Investigate solar pond technology (2:)

- Develop solar ponds (8:)

- Continue development of Algal-Bacterial Selenium Removal process (2:13-27)

- Continue research and development of subsurface-flow wetland treatment (2:27-29).

- Develop integrated biological, chemical, and physical treatment technology for cost-effectiveness and optimal objective accomplishment (2:27)

- Investigate selenium partitioning and isolation as a result of pond stratification (4:64-65)

- Establish groundwater management agency, develop management plan and gain plan approval (6:)
- Implement groundwater Management Plan (6:)

- Expand opportunities for salt separation and harvest (8:)

- Refine methods of salt separation and harvest (8:)

- Develop existing and new salt products and markets (8:)

- Develop existing and new selenium products and markets (8:)

[All Land Retirement TC recommended actions could be included]

8. Discussion of Interaction of Options and a Case Study

Introduction

In this chapter we examine a "case study" to suggest a process for evaluating drain water management options for a site. Second, we seek to identify drain water management options for lands in the case study area.

The case study is located within the Grasslands subarea of the San Joaquin Valley. The site's location is not of paramount importance, however; as noted above, our main intent has been to illustrate a process by which one can evaluate drain water options.

The topography of the area is dominated by two shallowly-sloping alluvial fans that drain the Coast Ranges to the west: the Little Panoche Creek alluvial fan, and the Panoche Creek alluvial fan. These geomorphic features are part of a whole series of alluvial fans that formed over millions of years along the eastward slope of the Coast Range.

The study site is plagued by shallow water tables. In that area, the groundwater table lies less than three meters (ten feet) below the ground surface. The subsurface drains have been installed over the years by farmers.

Table 4 shows the average maximum and minimum TDS concentrations measured in drain waters at sumps on lands in the vicinity of the transect. The TDS concentration at each measuring point varies over time, in response to the varying contributions of deep and shallow ground water, among other factors. To eliminate any such day-to-day or week-to-week variability, assume that each monthly measurement accurately represents an average TDS concentration of drain water for the corresponding month.

Young studied the selenium concentrations of drain water collected at some of the sumps in the area. The data were collected by water district personnel at varying intervals during the period from June 1991 to September 1994, rather than during the 1995–1996 period. The maximum and minimum selenium concentrations for a two-year period, 1992 to 1994, are shown in Table 4.

Table 4: Concentrations of TDS and selenium measured at drains near transect, 1992 to 1994. Adapted from maps by Young (Young, 1997).

Maximum TDS:	4500 to 7500 mg/l from middle to south end of transect; 7500 to 9000 mg/l at north end of transect
Minimum TDS:	3000 to 4500 mg/l, except at extreme north end of transect, where it's 6000 to 7500 mg/l
Maximum selenium:	0.1 to 0.4 mg/l from middle to south end of transect; 0.4 to 1.6 mg/l at north end of transect
Minimum selenium:	0.08 to 0.1 mg/l (all along transect)

Assessing the Technical Applicability of Management Options for the Study Site

When considering the various options, we will be guided by three overriding objectives:

1. Whenever possible, give priority to options that help grower to remain in production at a profit.
2. Always favor options that preserve the quality of the region's soils and ground water and protect fish and wildlife resources.
3. Whenever possible, choose options that enhance wildlife habitat and fisheries.

To help us apply these objectives to a situation, we use the following criteria when considering and evaluating each option:

- Meet water quality objectives in the San Joaquin River and comply with waste discharge requirements for drain outfalls into the river, or to evaporation ponds.
- Promote efficient use of water in the upslope portion of the area, in order to minimize drainage problem downslope.
- Utilize water until it's no longer reusable (e.g., sequential reuse), to reduce the volume of drainage that must be discharged.
- In view of the site's close proximity to the State and federal wildlife areas, as well as to private duck ponds, protect the environment for waterfowl.
- Choose options that foster improvement of water quality for fish.
- Avoid further contamination of groundwater so that it remains available in the future for potential agricultural, industrial, and municipal uses.

Interactions and Tradeoffs Resulting from the Simultaneous Application of Drainage Management Options

When more than one drain water management option is applied at a site, interactions and tradeoffs may occur. In this section, we examine briefly the possible one-to-one interactions between the eight options we are considering. (The numerous possible one-to-many interactions are not evaluated here. Such interactions are best evaluated by using a computer model, due to their complexity. We examined the available options in light of the primary "driving force" behind the decision-making process: the waste discharge requirements established by the CVRWQCB for discharge of drainage into Mud Slough and the San Joaquin River.

Drainage water reuse (DR) will reduce the volume of drainage water and thus help reduce the need for evaporation ponds (EP), groundwater management (GM), land retirement (LR), source reduction (SR), and river discharge (RD). However, DR could degrade groundwater if the concentrated drainage water is not intercepted and removed from the soil.

If drainage water is treated (DWT) and selenium or salts are removed from it, then there is less need for LR. Also, if selenium and salts are removed then there is more opportunity for evaporation ponds, river discharge and salt utilization (SU). On the other hand, source reduction and drainage reuse reduce the volume of drainage water to be treated.

If lands with high selenium in groundwater are retired, there is less problem water and less need for treatment, and reuse, groundwater management, evaporation ponds, river discharge and salt utilization. If evaporation ponds are feasible the need for land retirement, groundwater management and river discharge will reduce.

Source reduction will reduce the drainage volume needing management and discharge. GM can reduce the volume of drainage water leaving the farm and thus reduces the need for management and discharge. River discharge is determined by waste discharge requirement. All options mentioned above can help reducing salts and selenium and thus help meeting WDRs. Salt harvest and utilization can logically be a good option reducing the need for retiring lands and discharging to the river provided that salt can be produced and a market can be found. Reducing drainage water volume by reuse and storage in the aquifer (GM) as well as treatment will help the concept of salt utilization. A more expanded exemption of one-on-one interactions of options is given in the Appendix.

Integration: Selection of A Set of Options for the Study Site

In the first part of this section an overview of the process is developed for selecting a set of drain water management options. In the latter part, we do our best to choose a set of options for the study site, using presently available evaluation tools.

Flowchart of the Selection Process. Figure 6 is a flowchart depicting the process to select a set of drain water management options. Step 1 (box 1) on the flowchart is to gather technical and economic information about the site of interest. Step 2 is to evaluate the desirability of the options from a technical perspective. Step 3 involves ranking the site's options, based on technical desirability.

The next box in the flowchart is Step 4, an analysis of the relative *economic efficiency* of the various options. Essentially, in this step we seek to answer the question, "now that we know what we need to do, how can we get the best results for our money?" Marginal cost curves may be useful in determining which options are more efficient than others. When evaluating the economic efficiency of a highly complex, multi-parameter system, it may be advantageous to turn to a computerized economic optimization model. Section 4 of this report includes a brief description of some of these kinds of economic tools.

The course of action ultimately decided upon to solve a societal problem may run counter to what is economically efficient. That happens when a third group of criteria—policies or public benefits that are not easily quantifiable—are deemed more important. Evaluating such issues is the subject of Step 5 in the flowchart.

Methods for evaluating the public benefit issues involved in an environmental case study are beyond the scope of this report. We hope that it is enough simply to point out that investigation of such issues often is necessary and are considered in an environmental review process. A very brief introduction to this topic, as applied specifically to the drainage problems of the San Joaquin Valley, is provided in several chapters of the book *Economics and Management of Water and Drainage in Agriculture*, edited by Ariel Dinar and David Zilberman (Dinar and Zilberman, 1991). Chapter 37 of that book, by Rausser and Zusman, outlines a simple political economy model and examines several factors that explain how deterioration of soil and water quality can result directly from organizational failures and economic inefficiencies.

Step 6 of the flowchart is perhaps the most difficult. This phase of the selection process always involves intuitive judgement and a certain measure of creativity. Bringing all the information together and coming up with a stepwise path for implementing the favored options takes time. Step 7—preparing a report that describes the recommended options and the order in which they should be implemented—follows directly from Step 6.

Illustrative Application: Choosing a Set of Options for the Study Site Using Presently Available Tools. The selection of a set of drain water management options for the case study site probably is best accomplished by applying an appropriate economic optimization model. No such effort has been conducted to date for the study site. Consequently, in this section we propose a non-digital (non-computer) method for choosing a set of drain water options for the study site. The key tools used to develop this method are (1) our collective knowledge about the site and about available options—much of which has been described in this report, (2) intuitive judgement, (3) deductive reasoning, and (4) an assessment of the likely future trends in water quality regulations. We didn't follow the six steps outlined above, because more rigorous technical and economical evaluation and optimization would be necessary to prioritize options. Rather in this report the basis for feasibility of the eight options is as follows:

- Factor intuitive technical and economic considerations and the element of time. Specifically, favor available technology that can be applied economically in the forthcoming two or three years.
- Consider current practices that appear to be effective at managing drain water.

Table 5 shows each option indicates doability (relative to other options). Source reduction (SR) is in the top spot because it's very feasible, both technologically and economically, and it has been applied with success at the site.

Another, simpler alternative for expanding the use of RD is to implement a real-time drainage water disposal program. Assuming that some such program can and will be implemented, RD has been assigned a rank of "very effective."

Drain water reuse has been used in the study area and is viewed by many to be a viable option. In addition, though questionable in terms of its effects on long-term soil quality, drain water reuse does reduce the volume of drain water that must be managed. We assigned it the ranking of "Effective."

The flow-through wetland system, for treatment of drainage water, appears to show the most promise. It is relatively low in cost, yet fairly effective at reducing aqueous selenium concentrations. However, this form of drain water treatment has been implemented mostly on a pilot scale to date. The other technologies such as reverse osmosis do not at present appear to be any more feasible economically than the flow-through wetland. We gave drain water treatment overall a rank of "somewhat effective."

Retiring land will set aside land for wildlife habitat and as resting areas for migratory birds. For another, little legal barriers exist to prevent this option from being implemented. Other alternatives to land retirement including active land management may give the same results thus should be considered. When retiring land, water formerly used for irrigation of those lands is merely conveyed to nearby lands, then little improvement (in terms of reducing drain water quantity) will be achieved. Land retirement or intermittent fallow is practiced today in the region surrounding the study site, though not yet on the study site itself. The federal government has now made available funds for land retirement; implementation of this idea has begun to progress. We assigned it a rank of "somewhat effective."

Evaporation ponds would certainly decrease the volume of drain water; however, the mitigation measures and other measures necessary to meet the WDRs will be costly. The study area has relatively high selenium in ground water, which probably will result in higher-than-normal mitigation costs. For all these reasons, taken together, the evaporation pond option has been assigned a rank of "somewhat effective."

Although ground water management can play a major role in the study site's (and the Valley's) drainage problems, the management options available for ground water are all of a long-term nature and may be costly. In addition, ground water management efforts must be coordinated for the program to be successful. To ensure that a program will be effective, modeling will be necessary, with associated consulting and field monitoring activities. These will add to the cost. There are also the institutional issues including formation of organizations to coordinate the program. Additionally, State water quality laws forbid the intentional degradation of aquifers—a likely side effect of implementing this option. Ground water management has been assigned a rank of "somewhat effective."

Salt utilization (SU) has good long-term potential for helping to meet the salt balance in the Valley. However, when applying the criterion that says a technology must be doable "today" (i.e., within a time horizon of 2–3 years), and that a market exist, and that the economics be favorable, SU probably falls down the list. The realities of finding a profitable market and arranging economic harvesting and transport (e.g., by rail) are just not met, at present. Salt utilization is ranked "somewhat effective."

Note that Table 5 identifies the top three management options: source reduction ("Most effective"), river discharge ("Very effective"), and drain water reuse ("Effective"). The remaining five options are ranked equally in the moderate range ("Somewhat effective"), because there remains some question about the feasibility and cost of each.

Table 5- Rank of Drainage Management Options

Drainage Option	Rank
SR	Most effective of all
RD	Very effective
DR	Effective
DWT	Somewhat effective
LR	Somewhat effective
EP	Somewhat effective
GM	Somewhat effective
SU	Somewhat effective

Recommended Decision Tree

Figure 7 establishes a sequence of decisions for selection of the eight options for drain water management that were studied extensively by the eight Technical Committees. A number of other in-valley and out-of-valley management options not studied by the committees ought to be considered when devising an integrated plan for solving the drainage problem. The in-valley options include: (1) recognition of beneficial and reasonable uses of irrigation water while practicing source reduction, (2) changes in cropping pattern due to more extensive drain water reuse, and (3) changes in land use other than land retirement. If all of these in-valley management options are practiced and WDRs still are not met, other options should be considered: (4) the export of salts as brine into designated salt sinks, (5) modification of waste discharge requirements, and (6) other options including limitations on the importation of irrigation water and out-of-valley disposal options.

Figure 7 presents a "Decision Tree" that may be helpful in solving the drainage problem in the study area. To use the decision tree, one begins at "Start" and proceeds through the successive steps, as with a flowchart. As options fail to meet the WDRs, the succeeding options implemented become more drastic, or more costly, or both. In essence, looking at the chart differently, it displays combination of options, as the WDRs become more stringent. Combination of options should be selected based on technical, economical, and institutional issues discussed above. Figure 7 is an illustrative product for an analytical exercise for assessing potential drain water management options.

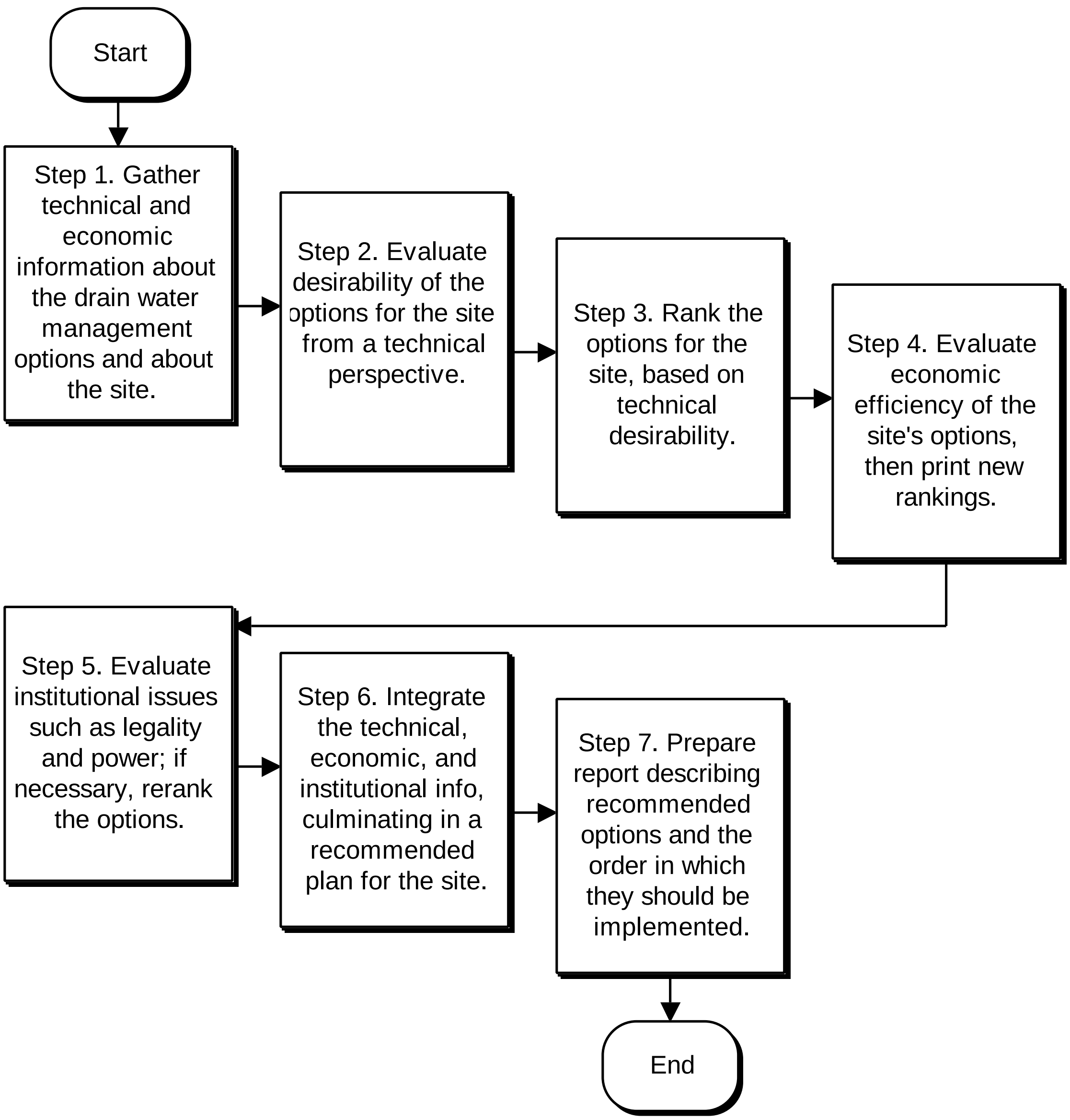


Figure 6: Flowchart of process for selecting an optimal set of drain water management options for a particular site.

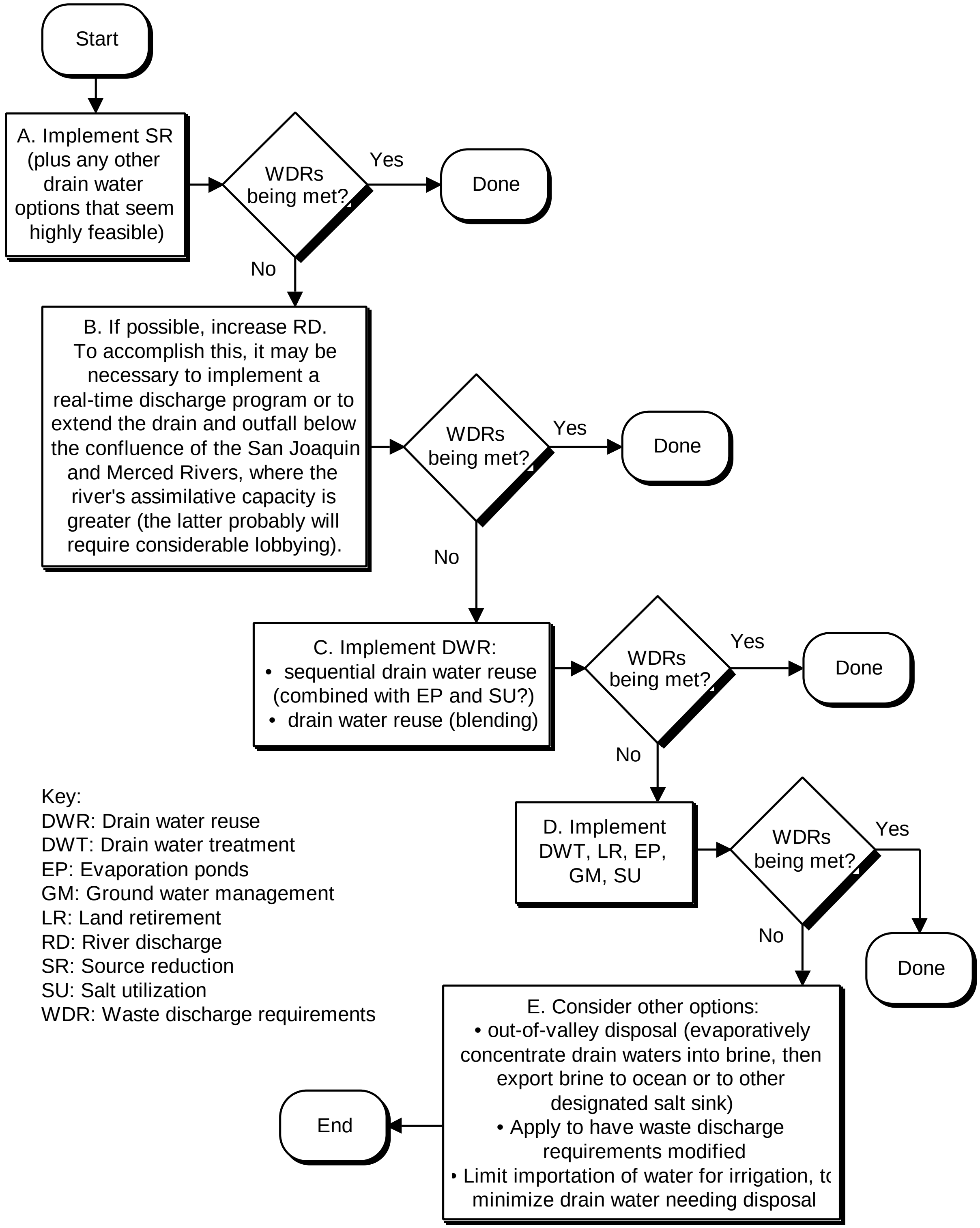


Figure 7: The "Decision Tree," a flowchart outlining a stepwise plan for implementing drain water management options at the case study site.

9 – Summary Recommendations

Status of the 1990 Management Plan Implementation

- Substantial progress has been made in all areas of recommendations with the exception of groundwater management.

- Acreage goals projected for 2000 by the 1990 Plan have not been attained, particularly in the areas of land retirement and drainage reuse, but progress continues.

Significant Changes since the 1990 Plan

- Modification of existing evaporation ponds for wildlife safety and the development of productive compensatory and alternative habitats have exceeded expectations.

- Drainage treatment, particularly with respect to reverse osmosis, is becoming sufficiently economical to consider inclusion in drainage management planning and implementation.

- Biological treatment methods hold promise and are deserving of further research and development.

- Opportunities exist for the utilization of recovered salt and selenium in conventional uses.

- The purposes and benefits of land retirement have been extended beyond selenium management, to restoration of wildlife habitat for endangered species and water transfers.

Overall Recommendations

Three categories of management options are necessary for achievement of a drainage solution: drainage reduction, drainage management, and an endpoint for salts and trace elements. A number of technologies for drainage reduction have been developed, significant progress has been made towards drainage management, and separation of salts from drainage water by solar evaporators has been demonstrated in a farm in Fresno County, but an endpoint for salt and trace elements for the entire westside of the Valley has not been resolved. Drainage water reduction and reuse are necessary steps. Drainage water treatment, such as reverse osmosis and flow-through wetlands, would make it possible to select an environmentally safe end point for salts. At the present time, evaporation ponds (and mitigation habitat), solar evaporators, lined ponds, and River discharge provide limited endpoint for salt and trace elements. Separation of salts and trace elements and identification of end points for these byproducts should continue. Potential uses of salts and marketing such products could offer an alternative or supplement the above disposal options. The potential uses of salts need to be investigated and marketing salts and selenium products should be studied. All disposal options have environmental, physical, and economical constraints. The environmental, technical and economical feasibility of these options merits further research. The three recommended course of actions follows:

Recommended Course of Action – Emphasis on Drainage Reduction

- The reduction of shallow groundwater levels through groundwater management by pumping remains a viable option; a specific plan for its implementation has been advanced by the Technical Committee.

- Implementation of land retirement pilot projects will require thorough monitoring and the application of adaptive management, possibly including limited irrigation, in order to achieve habitat restoration goals and avoid environmental impacts associated with salinization.

- Opportunities exist for further advances in source reduction, such as in improved management of crop use of shallow groundwater.

Recommended Course of Action – Emphasis on Drainage Reuse

- Research and development should continue on sequential and other forms of drainage reuse, such as forage crop production, and long-term sustainability of reuse systems.

- Additional commercial opportunities such as brine shrimp production in evaporation ponds, and marketing of treated drainage water (from reverse osmosis systems) should be expanded.

Recommended Course of Action – Emphasis on Salt Disposal and Utilization

- The primary focus of future efforts must be on the separation of salt from agricultural soils and shallow groundwater. Evaporation ponds and solar evaporators offer the best and in some cases only opportunity for salt separation at the present time.

- Emphasis must be placed on the marketing of salt and selenium, and the development of new salt and selenium products.

- Complementary to salt utilization, planning must continue on environmentally safe methods of salt disposal, including out-of-valley alternatives.

- Drainage treatment, specifically reverse osmosis, offers a further opportunity for salt separation, and integration with other options such as drainage reuse.

- For the Grasslands area, development of a system for real-time management of drainage discharge should continue.

Specific Recommendations

The government agencies should utilize the list of coordinated drainage management options presented in section 7 of this report as guidelines that could aid in formulating the future direction of agency drainage management programs. The list also provides funding agencies with specific tasks and subject areas that would be most efficacious in which to develop directed Request for Proposals and to grant funding. The specific recommendations are presented below. The details can be found in this report and in the Technical Committee and Subarea Committee reports.

Need For Planning and Financing

Listed below are some specific recommendations made in the 1990 Plan, that were to be implemented as soon as possible, but have not been accomplished:

- Investigate, in detail, measures that may be needed if stricter salt standards are established for the San Joaquin River/Delta.

- Both the Federal and State governments should explore ways of providing a portion of the financing needed to implement irrigator source-control actions and to invigorate existing programs. The U.S. Natural Resources Conservation Service, (NRCS), and U.S. Bureau of Reclamation both have programs that could aid in financing irrigator actions. The State of California, through the Department of Water Resources, the Department of Food and Agriculture, and the State Water Resources Control Board, could provide loans and grants for source-control actions, if funds were made available.

- The U.S. Department of the Interior and the State of California should jointly develop a technical assistance program to ameliorate the drainage problem, by providing water districts with geohydrologic and economic information and analytical techniques useful in investigating local areas for possible conjunctive surface- and ground-water use, land retirement, on-farm drainage, assessment, toxicity assessment, and habitat restoration.

- The State of California and the U.S. Department of the Interior should jointly consider the findings, forecasts, and plans of the Drainage Program with respect to drainage problems, and should look for opportunities to encourage amelioration and resolution of these problems. This should be achieved through ongoing operations, planning, construction, and - if considered necessary - new legislation, promulgation of rules and regulations, and appropriate language in contracts and administrative reviews.

- Within the State Water Project service area, the State of California should lead in planning for the regional drainage-water treatment and disposal needs that will arise from management and reuse of drainage water within local water districts.

- Within the Federal water service area, the Department of the Interior should lead in planning for the regional drainage-water treatment and disposal needs that will arise from management and reuse of drainage water within local water districts.

- Plans for installation and operation of well fields designed to pump from the semiconfined aquifer to lower the high water table should be completed cooperatively by Federal and State agencies and water districts. In the Federal service area, the Bureau of Reclamation should work with Westlands, Broadview, Panoche, San Luis, and Firebaugh Canal water districts to design well fields for areas identified in the 1990 Plan. In the State service area, the Department of Water Resources should work with Kern County Water Agency and Empire Westside, Riverside, Stratford, and Laguna irrigation districts, Lakeside Irrigation Water District, Kings County Water District, and Kings River Conservation District for the same purpose. Services of the U.S. Geological Survey should be used in locating favorable areas and in developing plans.

- To properly implement management of drainage and drainage-related problems, both the problems and the progress in solving them must be monitored. This is especially important because of the changing nature of the drainage problem and the flexible array of measures required for management. Monitoring all aspects of the problem and the effects of management will be critical to using the plan as a flexible guide to remedial actions.

Need for Technology Development

Listed below are some of the most important areas for new technology development that will facilitate advances in drainage management.

- New or adaptive techniques for the efficient means of separating salts from soils and drainage water in evaporation systems and achieving the necessary degree of purity for commercial marketing and utilization need to be developed.

- New sensors need to be developed that will enable continuous monitoring of selenium and boron concentrations in the San Joaquin River and tributaries to facilitate a real-time drainage discharge management system.

- Development needs to continue on all feasible and promising means of drainage treatment, particularly reverse osmosis and various biological systems in order to advance efficiency and reduce cost of operation.

- Much information exists for developing solar pond technology including operational guidelines, estimation of potential energy production, selenium exclusion from the solar pond food chain partitioning and isolation, and the eventual potential utilization of the salt content for other beneficial purposes or its proper disposal. However, economics of solar ponds and changing weather patterns in the Valley may present significant limitation to its implementation. These constraints should be further evaluated.

Need for Further Studies and Research

Listed below are some important areas in which additional studies and research are needed in order to make further advances in drainage management.

- Develop a better understanding of sediment biogeochemistry, organoselenium pathways, and selenium assimilatory capacities in order to develop temporal site-specific criteria that accurately reflects the bioaccumulation and toxicity of selenium speciation in the food chain. Combined with this study would be selenium mass balance studies to measure sources and sinks in aquatic ecosystems. The long-term ecosystem effect of selenium is another area for study. Also needed is refining methods of separating selenium from wildlife food chain.

- Research and demonstration projects on alternative and compensation habitats required to mitigate the evaporation pond impacts need to continue.

- Ongoing studies to minimize damage and impact on wildlife must be continued, especially studies leading to the establishment of site-specific criteria for selenium.

- Further research and development of methods for drainage treatment for the removal of salts should be vigorously pursued. Treatment is the key to solution of environmental problems associated with agricultural drainage.

- Continue research and development of new products made from agricultural salts and selenium, and studies on marketing those products. Also, continue research on environmentally safe and economically feasible end points for salts.

- Boron mass balance studies are also needed to determine boron sources and sinks in the ecosystem, and the sub-lethal and chronic impacts of boron on fish and other aquatic species.

- Work needs to continue on the refinement of computer models that can assist in developing drainage control and management strategies that will optimize the integration of source reduction, drainage reuse, and drainage treatment in a continuous real-time drainage management system.

- Research and development needs to continue on biological treatment systems for the removal of toxic elements, using flow-through wetlands and algal and microbial bioremediation.

- Techniques for the most efficient direct crop use of shallow groundwater, without increased soil salinization, need to be developed and implemented.

- Research needs to continue on developing site-specific drainage reuse system designs and marketable halophytic crops, and trees.

- Research needs to continue on land management strategies for retired lands that will minimize impacts from salinization and selenification of the soil, and will optimize post-retirement land use for wildlife habitat or other uses.

Need for Institutional Changes

Below are recommendations for important actions by government agencies that could facilitate drainage management.

- After the temporal and site-specific selenium studies described above, establish new site-specific regulatory criteria for selenium that accurately reflect the bioaccumulation and toxicity of selenium speciation in the food chain.

- Economically viable environmental regulations have to be developed to protect the environment, fish and wildlife, and keep agriculture in production. Regulators should set reasonable targets that both protect the environment, for both wildlife and agriculture, and are achievable. A policy driven by the goal of having high bird populations with the opportunity to have some bird impacts which are compensated for, increases the opportunity to use a combination of management options to sustain high agricultural productivity in the Valley.

- If the groundwater management option is to be implemented, a coordinated government agency program needs to be developed that will facilitate the monitoring, collection, analysis, and distribution of groundwater monitoring data, and will establish a program of groundwater pumping to simultaneously optimize shallow groundwater infiltration and usable water quality of the pumpage.

10- References

Belitz, K. and S. P. Phillips, 1995. Alternative to agricultural drains in California's San Joaquin Valley: Results of a regional-scale hydrogeologic approach, Water Resour. Res., 31.

Belitz, K. and F. J. Heimes, 1990. Character and evolution of the groundwater flow system in the central part of the western San Joaquin Valley, California, USGS Water Supply Paper 2348.

Brown and Caldwell Consulting Engineers. April 1987. Screening Potential Alternative Geographic Disposal Areas.

Bull, W.B., and R.E. Miller, 1975. Land subsidence due to groundwater withdrawal in the Los Banos- Kettleman City area, California, 1, Changes in the hydrologic environment conducive to subsidence, U.S. Geol. Surv. Prof. Pap., 437-E.

California Department of Water Resources. 1992-1996. Drainage Monitoring Reports.

California Department of Water Resources. May 1957. The California Water Plan, Bulletin 3.

California Legislature, Committee on Water Problems. March 1957. Drainage Problems of the San Joaquin Valley of California, 10th Partial Report.

Central Valley Project Improvement Act. Title XXXIV. 1992. Central Valley Project Improvement Act, Public Law Westlaw Congressional Record Database.

California Regional Water Quality Control Board, Central Valley Region. February 1998, Loads of salts, boron, and selenium in the Grasslands Watershed and Lower San Joaquin River, Volume I- Load Calculations.

Davis, G.H. and J.F. Poland, 1957. Ground-water conditions in the Mendota-Huron area, Fresno and Kings Counties, California, U.S. Geological Survey Water-Supply Paper 1360-G, p 409-588.

Dinar, A. and Zilberman, D. (eds.) 1991, The Economics and Management of Water and Drainage in Agriculture. Kluwer Academia Publishers, Boston, Massachusetts, 946 pages.

Gilliom, R. J., and others, 1989. Preliminary assessment of sources, distribution, and mobility of selenium in the San Joaquin Valley, California: U.S. Geological Survery Open-File Report 88-4186.

Gronberg, J. M., K. Belitz, 1992. Estimation of a water budget for the central part of the western San Joaquin Valley, California, U.S. Geol. Surv. Water-Resour. Invest. Rep., 91-4191.

Gronberg, J.M., K. Belitz, S.P. Phillips, 1990. Distribution of wells in the central part of the western San Joaquin Valley, California, U.S. Geol. Surv. Water-Resour. Invest. Rep., 89-4158.

Hanson Environmental, Inc. 1993. Tulare Lake Drainage District North, Hacienda, and South Evaporation Basins – Kings County Site-Specific Biological Impact Analysis and Response to Comments. Prepared for California Regional Water Quality Control Board, Central Valley Region. June 1993.

Hanson, C. 1995. Testimony of Dr. Charles Hanson to the California State Water Resources Control Board in response to petitions regarding Tulare Lake evaporation ponds.

Johnson, A.I., R.P. Moston, and D.A. Davis, 1968. Phsyical and hydrologic properties of water-bearing materials in subsiding areas in central California, U.S. Geol. Surv. Prof. Pap., 497-A.

Knapp, K.C. "Economics of Salinity and Drainage Management Regional Integrated Models." UC Riverside, August 27, 1999.

Linsley, R.K., Jr., M.A. Kohler, and J.L.H. Paulhus, 1975. Hydrology for Engineers, McGrow-Hill, New York.

Miller, R.E., J.H. Green, and G.H. Davis, 1971. Geology of the compacting deposits in the Los Banos-Kettleman City subsidence area, California, U.S. Geol. Surv. Prof. Pap., 497-E.

Page, R.W., 1986. Geology of the fresh groundwater basin of the Central Valley, California, with texture maps and sections, U.S. Geol. Surv. Prof. Pap., 1401-C.

Rantz, S.E., 1969. Mean annual precipitation in the California region, U.S. Geol. Surv. Open File Maps. San Joaquin Valley Drainage Program (SJVDP). 1990. A Management Plan For Agricultural Subsurface Drainage and Related Problems on the Westside San Joaquin Valley. Prepared by San Joaquin Valley Drainage Program.

San Joaquin Valley Drainage Program, 1990. Technical Information Record.

San Joaquin Valley Drainage Implementation Program. December 1991. A Strategy for Implementation of the Management Plan for Agricultural Subsurface Drainage and Related Problems on the Westside San Joaquin Valley.

San Joaquin Valley Interagency Drainage Program (USBR, DWR, SWRCB). June 1979. Agricultural Drainage and Salt Management in the San Joaquin Valley.

San Joaquin Valley Drainage Implementation Program, 1999a. Drainage Reuse Technical Committee Report.

--------, 1999b. Drainage Treatment Technical Committee Report.

--------, 1999c. Land Retirement Technical Committee Report.

--------, 1999d. Evaporation Pond Technical Committee Report.

--------, 1999e. Source Reduction Technical Committee Report.

--------, 1999f. Groundwater management Technical Committee Report.

--------, 1999g. River Discharge Technical Committee Report

--------, 1999h. Salt Utilization Technical Committee Report.

--------, 1999i. Grasslands Subarea Report.

--------, 1999j. Westlands Subarea Report.

--------, 1999k. Tulare/Kern Subarea Report.

Schmidt Personnel Communication, 1998.

Swain, W.C., 1990. Estimation of shallow ground-water quality in the western and southern San Joaquin Valley, California. Technical Information Record for the San Joaquin Valley Drainage Program, Sacramento, California, September, 1990.

U.S. Bureau of Reclamation, 1978. Special Task Force Report on San Luis Unit. P. 174.

U.S. Bureau of Reclamation, 1956. Central Valley Project; A Report on the Feasibility of Water Supply Development.

U.S. Department of the Interior Interagency Land Retirement Team, 1999. Final Environmental Assessment.

U.S. Fish and Wildlife Service, 1995a. Alternative Habitat Protocol for Drainwater Evaporation Basins.

U.S. Fish and Wildlife Service, 1995b. Compensation Habitat Protocol for Drainwater Evaporation Basins.

Williamson, A.K., D.E. Prudic, and L.A. Swain, 1989. Groundwater flow in the Central Valley, California, U.S. Geol. Surv. Prof. Pap., 1401-D.

Young, C.A.. Spatially Distributed Water and Solute Balance: Panoche Water District. 1997. Master Thesis at UC Davis. Internet URL: http://excitement.ucdavis.edu/Chuck/Thesis/Abstract.htm

11 Appendix

Interactions of Drainage Management Options

When more than one drain water management option is applied at a site, interactions and tradeoffs may occur. In this section, we examine briefly all the possible one-to-one interactions between the eight options we are considering. (The numerous possible one-to-many interactions are not evaluated here. Such interactions are best evaluated by using a computer model, due to their complexity.)

In the paragraphs that follow, we refer to each pair of options by using simple shorthand: we show the symbols for the two options, plus a lower-case “x” in between.

DR

Drain water reuse will reduce the volume of water that needs to be managed. It also probably will reduce the total mass of salt and selenium requiring discharge, because of sinks in the reuse system. However, the concentration of residuals from drain water will be higher when drain water is reused than when it is not; this could make meeting concentration-based waste discharge requirements more difficult.

DWT

Drain water treatment has the potential to remove constituents of concern, through chemical, physical, and biological processes. Using present technologies, salinity, boron, and molybdenum concentrations can be reduced to levels low enough to meet waste discharge requirements. The same cannot be said for selenium. With the exception of constructed flow-through wetlands, present technologies for removing selenium cannot meet the waste discharge requirement of 5 micrograms per liter (4-day average) at Mud Slough, the outfall point.

DWT x DR

Combining drain water reuse with drain water treatment may not help growers in the vicinity of the transect meet the waste discharge requirements for selenium at Mud Slough any better than would either of these management options alone. The limited selenium removal capacity of treatment methods, even of flow-through wetlands, is not greatly dependent on initial concentration. In addition, drain water reuse will, if anything, increase those initial concentrations.

LR

Land retirement will reduce the volume of drain water that must be managed, provided that the water formerly used to irrigate the retired parcel is not applied on other irrigated lands in the region.

LR x DR

If you retire land, there would be less need for drain water reuse. Conversely, if you have already implemented drain water reuse, then less land retirement would be needed to meet the waste discharge requirements.

LR x DWT

If you retire land, there will be less drain water needing treatment. Conversely, if you treat drain water, less land need be retired in order to meet waste discharge requirements.

EP

This option provides an alternative disposal system for drain water—the evaporation pond. That's a different approach from the first three options examined above—those were for managing drain water. In the vicinity of the transect, because of the high level of selenium in the drainage water, evaporation ponds are more likely to be hazardous for waterfowl than ponds in most other regions. The waste discharge requirements for the ponds and the mitigation measures imposed likely will be more stringent than in other regions. (These pond-related waste discharge requirements probably will act as a secondary "driving force" for deciding which options are best. Because this extra criterion adds to the monitoring requirements and increases costs, for lands in the study site evaporation ponds may end up ranked lower than other options.)

EP x DR

In the particular case of sequential reuse, the residual water is disposed of in a solar pond, a special type of evaporation pond. If drain water from lands in the study area is discharged to one or more evaporation ponds and simultaneously drain water is being reused, the need for drain water discharge to the river is reduced considerably. This makes it easier to meet the waste discharge requirements that regulate and limit the disposal of drain water to the river.

EP x DWT

In Tulare Lake Drainage District's constructed flow-through wetland system, selenium is removed in the wetland's cells so that outflow from the cells is less hazardous when disposed of in evaporation ponds. Such a system might work well at the study site, where selenium concentrations in drain water are among the highest in the San Joaquin Valley.
Evaporation ponds are not advantageous when the treatment processes employed are for removal of salts and not for selenium.

EP x LR

Implementation of evaporation ponds requires dedicating some lands for the construction of ponds, so in a sense you've retired some land. Typically, however, we think of land retirement as reversion of land to a natural state. Implementation of a land retirement program will reduce the amount of drain water needing discharge or disposal, reducing, in turn, any need for evaporation ponds.

SR

Source reduction is considered by many to be the preferred drain water management option, for a variety of reasons. It's relatively easy for many growers to implement because it often fits in well with growers' other efforts to manage water more efficiently.

SR x DR

When limitations on drain water discharge exist, drain water reuse is a natural (i.e., logical) follow-up to source reduction. Moreover, if root-water extraction is practiced, the volume of drain water needing discharge will be reduced further. Reuse of drain water without source reduction will result in excessive volumes of drain water that need to be managed.

SR x DWT

When there are difficulties meeting waste discharge requirements, the combination of source reduction and drain water treatment will help meet the WDRs. If you don't do source reduction, then the volume of drain water that needs to be treated increases.

SR x LR

If source reduction is practiced, the area of land that needs to be retired will be minimized. If land retirement is implemented, there will be less need for source reduction. Upslope source reduction reduces the drainage and shallow water table-related problems downslope.

SR x EP

Reducing deep percolation by implementing source reduction helps to reduce the volume of water that must be disposed of in evaporation ponds. If source reduction is not practiced widely, you'll have to build larger (or more) evaporation ponds.

GM

Managing ground water requires a comparatively long period to observe benefits; the impacts would not be felt fully for many months or years—and under some scenarios, not even for decades. If the quality of ground water pumped is marginal, then waste discharge requirements will be more difficult to meet. Pumping of deep aquifers to manage drain water (a shallow resource) probably will require longer time periods than the pumping of shallow ground water. The environmental effects of such pumping are complex and difficult to assess. The pumping of shallow ground water to lower the ground water table and reduce the volume of drainage water will require an extensive network of wells if it is to be effective.

GM x DWR

Drain water reuse can have both positive and negative effects on ground water. On the one hand, reuse of drain water minimizes the need for management of ground water by pumping. On the other hand, reuse can result in further degradation of shallow ground water. Under certain conditions, pumping of ground water to lower the ground water table can provide a source of relatively fresh water for blending with reused drain water.

GM x DWT

Ground water management and drain water treatment act on two different bodies of water. Therefore, these two options are somewhat isolated from one another and the pathways of interaction are relatively indirect.

If ground water management is implemented successfully and widely, there will be less drain water needing treatment. If drain water treatment is implemented successfully and widely, there will be less need for ground water management in order to meet waste discharge requirements at Mud Slough.

GM x LR

If you retire land, there is less need for ground water management, because you've reduced the source. Conversely, if you implement a successful ground water management program, there is less need for land retirement. The combination of these two options requires careful modeling to determine where and when to pump and to retire land. Several studies thus far have shown that the decision about whether to retire in contiguous blocks or in a patchwork fashion, and the decision about where to pump—upslope or downslope, shallow or deep—determine whether the program will be successful in the long run.

GM x EP

Water disposed of in evaporation ponds consists entirely of effluent from tile drains: in other words, it is a mixture of intercepted shallow ground water and deep percolation water. Lowering of the shallow ground water table by successful implementation of a ground water management program would reduce the amount of intercepted shallow ground water, reducing, in turn, the total volume of drain water needing to be discharged to evaporation ponds.

A solar evaporator—a type of evaporation pond—is used to dispose of the highly saline water left over from sequential reuse of drain water. Construction of such ponds in the vicinity of the study site will provide an additional place to discharge drain water, thereby reducing the need for ground water management efforts aimed at lowering the shallow ground water table.

GM x SR

Implementation of a source reduction program helps to minimize the need for ground water management. The converse is not necessarily true. Implementing a ground water management program probably will not reduce the need for source reduction.

In some areas of the study site, ground water may prove to be low enough in salt that it can be used as a replacement for surface supplies of irrigation water. pumping of such water for irrigation (i.e., conjunctive use of ground water and surface water) would help to reduce the volume of drainage water needing management, especially if source reduction measures also are practiced. Increasing the pumping of ground water may accelerate the downward movement of shallow, high-salinity water, which may have adverse effects on the quality of ground water aquifers.

RD

Presently, some of the drain water from the study site is discharged via the Grassland Bypass Project to Mud Slough, which empties into the San Joaquin River. The waste discharge permit issued by RWQCB specifies maximum concentration levels and maximum mass loads for selenium at Mud Slough and at several points downstream on the San Joaquin River. Those requirements limit the volume of drain water that can be discharged. For river discharge to be used more extensively as a drain water management option, either the drain water must be treated to reduce its selenium content or the load limit would need to be made less stringent. The latter is not likely, because the present waste discharge permit specifies maximum concentration and mass loading targets for selenium for several years into the future, and those projected targets become more stringent over time, not more lenient.

As stated at the beginning of this section, the waste discharge requirements for river discharge of drain water are the principal "driving force" for evaluating all other drain water management options and combinations of options. Because river discharge is already our driving force for evaluating other options, we will not show the various combinations explicitly (again) here.

SU

Because of the imbalance between salt input and salt output from the region, salinity is a major focus for efforts to preserve the future of irrigated agriculture, as well as wildlife habitat. To rebalance the salt equation, salt must be removed from the region, either by discharge with water down the San Joaquin River or by other forms of removal. Perhaps the most feasible non-river method of removal is salt harvest and utilization. Evaporation ponds and solar ponds are presently the most economical methods for separating salts from water. To be implemented successfully at the study site over the long term, technologies and markets for utilization of those salt deposits must be pursued and found.

SU x DWR

If you can find ways to utilize the salt, then sequential drain water reuse becomes a valuable part of the utilization process. So reliance on those will likely increase. If reusing drain water to blend with other waters for irrigation (i.e., reuse methods other than sequential reuse), then there's less need for salt harvesting and utilization.

SU x DWT

If you implement a program to treat drainage waters to remove salt, then the resulting brine could potentially serve as the feedstock for a salt-harvesting process. If you plan on utilizing salt and have constructed processes for doing so, you probably won't implement any of the drain water treatment processes outlined earlier in this chapter solely as a means of harvesting salt, because all of those processes are relatively expensive. Instead, you would probably rely on evaporative processes, such as an evaporation pond or a solar pond, for harvesting salt.

SU x LR

If large-scale processes for utilizing salt prove to be both feasible and economical (with a variety of available markets for selling or otherwise distributing salt), then there would be less need for land retirement. If you implement a land retirement program, there's less need to harvest and utilize salt.

SU x EP

Presently, the most economical means of harvesting salt involves using some form of evaporation ponds. Therefore, increased reliance on salt utilization processes implies that there will be a concomitant increased need for evaporation ponds. (These two options are closely linked.)

SU x SR

If you implement source reduction, there will be less drain water and less salt needing to be harvested and utilized. Efforts to harvest and utilize salt have little effect on efforts to reduce the sources of drain water and deep percolation. (The two are not closely linked.)

SU x GM

If you could harvest and utilize large quantities of salt (megatons per year), the region's ground water quality would improve slowly over time. The need for ground water management as a way to reduce drain water discharge probably would be lessened. Pumping of saline ground water can be a source of salts for harvest and utilization. Some shallow ground water at the site has very high salinity, with an average electrical conductivity (EC) of 10 dS/m, equivalent to a total dissolved solids (TDS) content of about 8,000 ppm.

SU x RD

If you find ways to harvest and utilize salt, there will be less drain water—and less salt—to discharge to the river. Conversely, if you find ways to discharge more salt into the river, there will be less drain water **a**nd less total mass of salt for harvest.

C:\alemi\wpdocs\activity\ahcc\162000ahccrpt.doc

.